GUIDEBOOK NO. 13

SAMPLING THE LAYER CAKE THAT ISN'T: THE STRATIGRAPHY AND PALEONTOLOGY OF THE TYPE-CINCINNATIAN

Richard Arnold Davis and Roger J. Cuffey, Editors

originally prepared for the 1992 Annual Meeting of the Geological Society of America

Columbus 1998

DIVISION OF GEOLOGICAL SURVEY
4383 FOUNTAIN SQUARE DRIVE
COLUMBUS, OHIO 43224-1362
(614) 265-6576
(614) 447-1918 (FAX)
e-mail: geo.survey@dnr.state.oh.us
World Wide Web: http://www.dnr.state.oh.us/odnr/geo_survey/

STATE OF OHIO
George V. Voinovich, Governor
DEPARTMENT OF NATURAL RESOURCES
Donald C. Anderson, Director
DIVISION OF GEOLOGICAL SURVEY
Thomas M. Berg, Chief

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Contributors:

Roger J. Cuffey
Department of Geosciences
Pennsylvania State University

Benjamin F. Dattilo
Geoscience Department
Weber State University (Ogden, Utah)

Richard Arnold Davis
Biology Department
College of Mount St. Joseph (Cincinnati)

Sharon C. St. Louis Diekmeyer
Department of Geology
University of Cincinnati

Lawrence I. Goldman
MINEsoft, Ltd.
Lakewood, Colorado

Donald E. Hattin
Department of Geological Sciences
Indiana University

Helen B. Hay (deceased)
formerly *Geology Department*
Earlham College

Steven M. Holland
Geology Department
University of Georgia

Brian Kirchner
Geology Department
Earlham College

Lynn A. Rockwell
Department of Geosciences
Pennsylvania State University

Gregory A. Schumacher
Division of Geological Survey
Ohio Department of Natural Resources

Douglas L. Shrake
Division of Geological Survey
Ohio Department of Natural Resources

Richard A. Spohn
Geology/Physics Library
University of Cincinnati

E. Mac Swinford
Division of Geological Survey
Ohio Department of Natural Resources

Stanley M. Totten
Department of Geology
Hanover College

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CINCINNATI

DIVISION OF GEOLOGICAL SURVEY

OHIO DEPARTMENT OF NATURAL RESOURCES

Typesetting, layout, and revision of some figures by Lisa Van Doren
Revision of some figures by Robert L. Stewart

Cover photo: E. O. Ulrich, in the type-Cincinnatian along the Ohio River below Covington, Kentucky. The photograph was taken in 1901 by R. S. Bassler (see Geotimes, v. 30, no. 9, p. 12, and v. 30, no. 12, p. 2); according to Ellis L. Yochelson, a print of this photograph, from Dr. Bassler, is in the archives of the Smithsonian Institution. Photo courtesy of Tom Gathright, Virginia Division of Mineral Resources, and of the Virginia Department of Environmental Sciences, Virginia Museum of Natural History at the University of Virginia, who own a lantern slide of the image.

CONTENTS

LOCALITIES AND UNITS

INTERPRETATIONS

APPENDIXES

PREFACE

This guidebook was produced for use on a two-day field trip held in conjunction with the 1992 Annual Meeting of the Geological Society of America in Cincinnati. At that time, because of time constraints, only enough copies of the guidebook were produced to distribute to field-trip participants. The intention was to publish a typeset version for general distribution after the meeting. Unfortunately, the process took rather longer than originally intended. In the intervening years, progress has been made in the study of type-Cincinnatian rocks. However, we have not endeavored to update the entire contents of the volume. Citations of publications that were "in press" in 1992, but subsequently have made it "in print," have been modified. Typographical errors have been corrected, and some authors have chosen to make a few, mostly minor, alterations in their respective chapters. Many of the figures have been redone by the cartographic staff of the Division of Geological Survey. The bibliography has been augmented, but no comprehensive literature search for recent publications was undertaken.

In the years subsequent to the field trip, Helen Hay, one of the authors of several chapters in this volume, died. She was certainly a leading authority on the geology of the Cincinnatian rocks on the west side of the Cincinnati Arch. She will be missed. We dedicate this volume to her memory.

1. AN INTRODUCTION TO THIS VOLUME

by
Richard Arnold Davis

"Oh, No! Not more on the Cincinnatian!"—I hear your plaintive cry. "It's been done." "We solved it all years ago." Well, maybe.

This volume is not a standard road-log guidebook. Instead, the localities are arranged by the stratigraphic units to be seen, beginning at the bottom of the type-Cincinnatian and ending, strangely enough, at the top. Each locality paper is modeled somewhat after those in the Decade of North American Geology Centennial Field Guides of the Geological Society of America.

Partly because various localities expose various thicknesses of the column and various units, a given locality may be mentioned in more than one paper in the volume. In order to keep track of these localities and to avoid ambiguity in citing them in the various papers, each locality has a locality number. The format for these designations is OH-HA-0001. The first two letters refer to the state in which the locality lies, in this case, Ohio. The state designation is followed by a county designation, here Hamilton County. The concluding four-digit number is the locality within the county. Only for the principal locality or localities (fig. 1-1) for each locality paper are location details given in that paper. Otherwise, such information is relegated to the locality list (Appendix A) at the end of the volume.

In addition to the several "locality papers," there are three of what might be termed interpretational papers. The first of these, by Gregory A. Schumacher, summarizes the perspectives and conclusions that have underlain and resulted from the recent work by the Ohio Division of Geological Survey in the Cincinnatian rocks of the state. Then follows like coverage by Helen B. Hay, dealing especially with the Cincinnatian rocks of eastern Indiana and western Ohio. Finally, there is a discussion by Steven M. Holland of the rocks of the type-Cincinnatian from the perspective of sequence stratigraphy.

The volume closes with a lengthy bibliography of works on the type-Cincinnatian (Appendix B). Each paper also has its own list of references cited. The appendicular bibliography does not include all the references cited in the various papers in the volume, but, rather, only those on the type-Cincinnatian. There are, however, many references in the volume bibliography that are not cited in any of the papers in the volume.

Some readers may click their tongues and shake their heads about the sloppy use of the term "shale" in this volume. Although it is a deeply seated tradition to speak of the rocks of the type-Cincinnatian as a sequence of interbedded limestones and shales, the local "shales" most generally lack the fissility that characterizes shale, *sensu stricto*. In short, the local "shales" probably should be referred to as claystones or mudstones. Nonetheless, the various authors in this volume generally have bowed to the hoary, shaly tradition.

Another minor frustration will result from the issue of formal stratigraphic units vs. informal stratigraphic units. In the literature as a whole, different authors have chosen to designate informal units in different ways. Some workers have done so by putting the initial letter of the unit part of the name in lower case, for example, Brookville formation (as opposed to the formal unit, the Kope Formation). Unfortunately, subsequent authors (and editors?) not always have been so careful as to keep that initial letter lower case. Hence, we have chosen also to put quotation marks around the names of informal units, for example "Brookville formation," so that it will be obvious to the reader that there is something unusual about the unit name so flagged (and not just sloppy proofreading).

On the other hand, we have chosen not to have a mere proposed change in rank affect the formality of a unit name; for example, neither Corryville Formation nor Corryville Member displays the visible stigmata of informality.

Another, larger dose of potential frustration almost certainly will result from the fact that various authors in the volume have chosen to use different schemes of stratigraphic nomenclature. This, too, is a well-established tradition in the study of the rocks of the type-Cincinnatian.

Would that this volume be a real step toward a greater understanding of the geological reality recorded in the rocks of the type-Cincinnatian and toward the adoption of a single scheme of stratigraphic nomenclature that truly and accurately reflects that reality!!

Address of author: Richard Arnold Davis, Biology Department, College of Mount St. Joseph, 5701 Delhi Avenue, Cincinnati, OH 45233-1670.

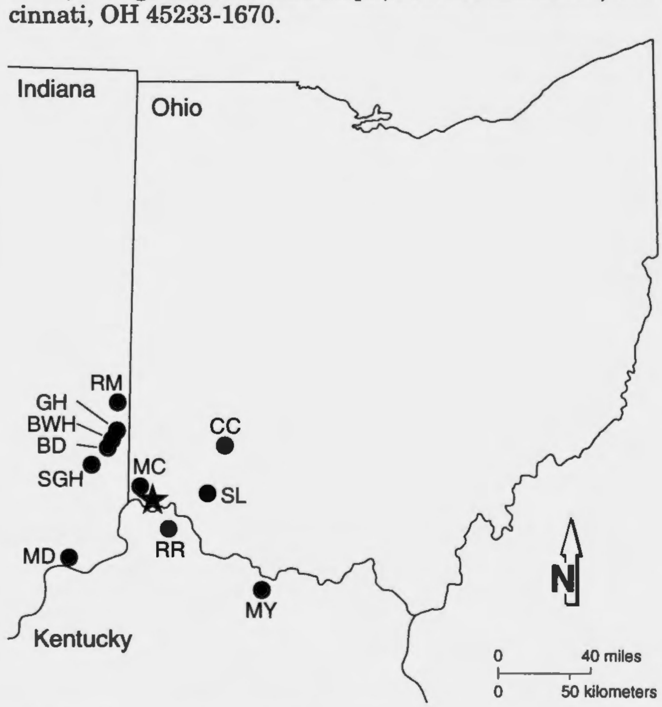


FIGURE 1-1.—Map of the tri-state area showing major locations described in the locality papers (papers 3-15) in this guidebook. ★ = central Cincinnati area; BD = Brookville Dam (paper 8); BWH = Bon Well Hill (paper 10); CC = Caesar Creek (paper 13); GH = Garr Hill/Brookville North (paper 11); MC = Miamitown-Cleves (papers 4, 7); MD = Madison (papers 6, 14); MY = Maysville (paper 5); RM = Richmond (paper 15); RR = Riedlin Road/Mason Road (papers 3, 7); SGH = South Gate Hill (paper 12); SL = Stonelick Creek (paper 9).

2. AN INTRODUCTION TO THE TYPE-CINCINNATIAN

by
Roger J. Cuffey

Paleontologists recently have developed great interest in detailed studies of the tempo, mode, rate, and pattern of evolution. Such studies require abundant fossils and thick stratigraphic sections representing millions of years of uninterrupted sedimentation; the type-Cincinnatian should provide many excellent opportunities. Comparable sequences elsewhere have permitted initial documentation (Cuffey, 1967, p. 37-39, 85-86) and later confirmation (Pachut and Cuffey, 1991; Pachut and others, 1991) of gradual evolution within trepostome bryozoans. Preliminary studies of certain type-Cincinnatian trepostomes (Brown and Daly, 1985), by methods whose value has been re-emphasized (Cuffey and Pachut, 1990), have indicated similar phyletic trends and so hold much interest for future investigations.

Type-Cincinnatian fossils (fig. 2-1), even though well known, have yielded less of this kind of information than might be expected. Personal experience with Cincinnatian bryozoans suggests that one significant cause of this situation has been confusion generated by inadequacies and inconsistencies in the type-Cincinnatian stratigraphic literature and usage. However, careful examination of that literature and appropriate field localities indicates that the differences in terminology and classification actually have much in common. In fact, a coherent, though complicated integration of many previous studies does provide a pragmatically useable framework (Errett and Cuffey, 1989) for investigating type-Cincinnatian bryozoans; this integration involves paleoecologic interpretations (fig. 2-2), stratigraphic correlations (fig. 2-3), paleoenvironmental distributions (fig. 2-4), and derivative conclusions such as depth curves (fig. 2-5) and regional profiles (such as fig. 5-3 of Cuffey, paper 5 in this volume).

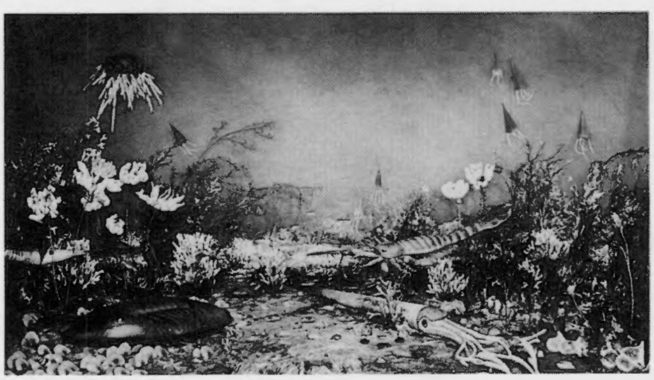


FIGURE 2-1.—Diorama reconstruction of shallow marine habitat characteristic of the Cincinnati area during the Late Ordovician. Courtesy of Cincinnati Museum of Natural History; the diorama was constructed about 1959 by noted museum artist Paul Marchand, under the direction of K. E. Caster.

The type-Cincinnatian consists of thin, interbedded limestones and shales that appear much alike at first glance but which exhibit subtle differences that have paleoecologic implications (fig. 17-2, Hay, paper 17 in this volume; Schumacher, paper 16 in this volume; and references in both). The fossiliferous limestone beds commonly have been interpreted as storm-lag (tempestite) deposits, although such lags obviously were modified by between-storm invertebrate encrustation and growth so as to produce complex and varied carbonate beds (Anstey and Fowler, 1969; Harris and Martin, 1979; Kidwell and Aigner, 1985; Kidwell, Fürsich, and Aigner, 1986). If deposition of the limestones was indeed storm related, higher percentages of limestone beds within a succession indicate more frequent penetration by storm waves and, hence, shallower water depths, whereas higher shale percentages imply deeper waters (Hay, paper 17 in this volume, and references therein). "Deeper," however, is only relative; the entire Cincinnati region was quite shallow throughout the Cincinnatian Epoch and was characterized by gentle slopes, holes, and shoals, and depths ranging from as little as one or a very few meters (or feet) (Hatfield, 1968, p. 12-13, 20; Ettensohn and others, 1986, p. 210, 214; Cuffey, paper 5 in this volume) to on the order of 20, 25, 30, or perhaps 50 meters (60-150 ft) (Bucher, 1917, p. 288, 290; Anstey and Fowler, 1969, p. 674-675; Anstey and others, 1987, p. 166-167; Brown and Daly, 1987; Weir and others, 1984, p. 96-97).

Critical to evolutionary studies is clarification of type-Cincinnatian stratigraphic relationships, including vertical successions, lateral facies, biochronologic correlations, and extent of disconformities. Moreover, the ranges of a great number of Cincinnatian species are recorded in terms of

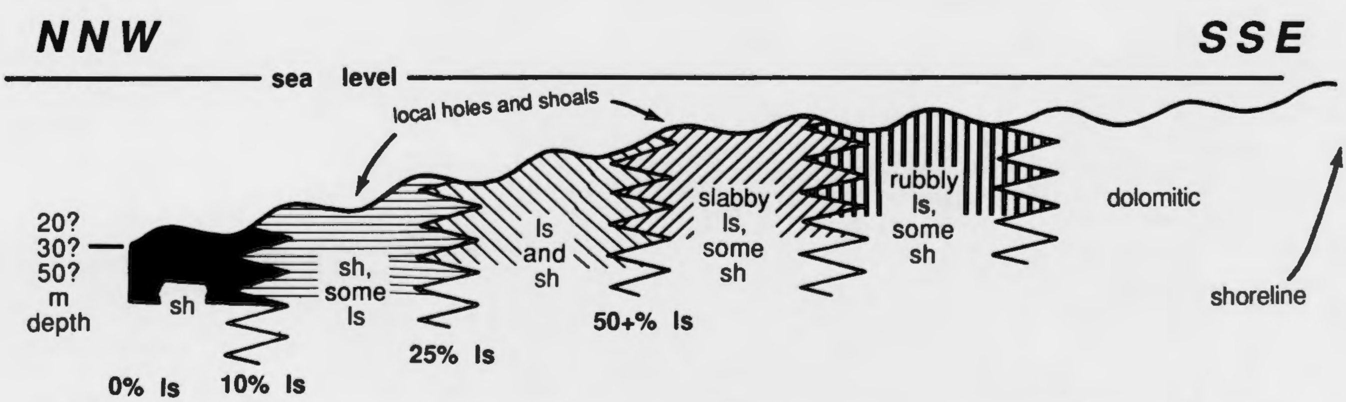


FIGURE 2-2.—Diagrammatic summary of paleoecologic interpretations of the major type-Cincinnatian facies groups; the stimuli of Hay and others (1981) and Weir and others (1984) are acknowledged.

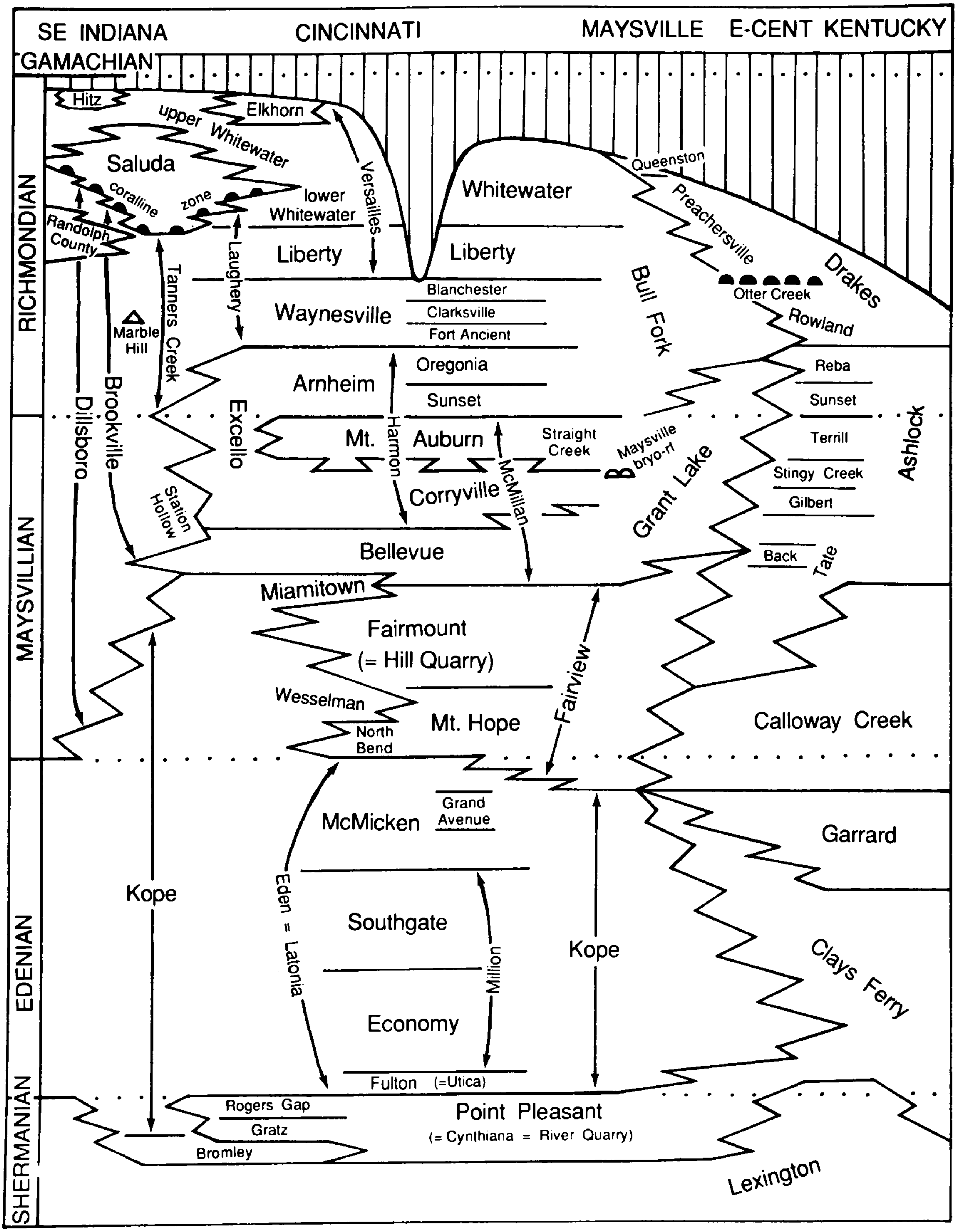


FIGURE 2-3.—Correlation chart showing the type-Cincinnatian stratigraphic units that have been employed in recording bryozoan species ranges; the influences of Pojeta (1984), Sweet (1979), Hay and others (1981), and Caster, Dalvé, and Pope (1955) are acknowledged.

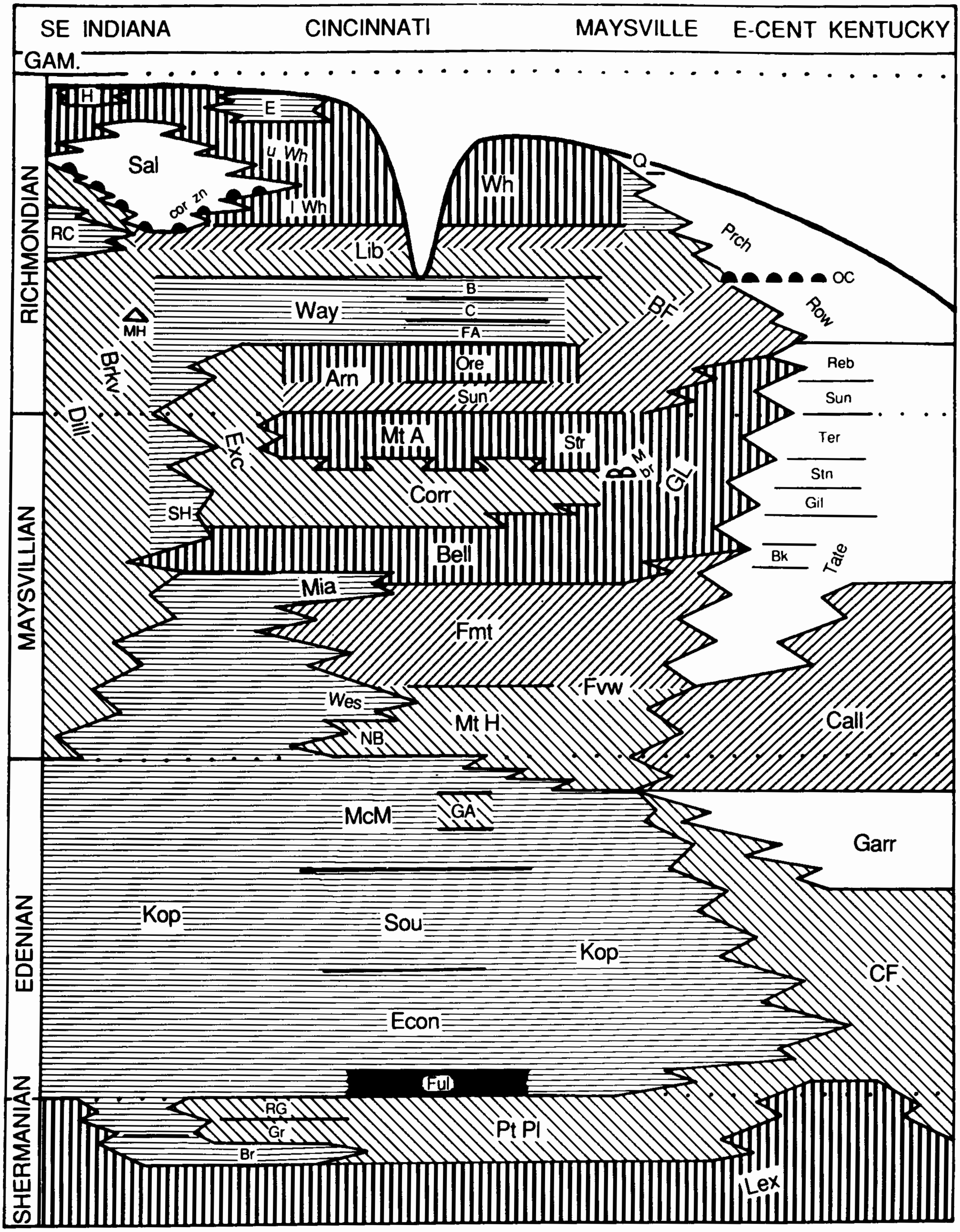


FIGURE 2-4.—Distribution of paleoenvironments within the type-Cincinnatian; patterns are those shown on figure 2-2; unit boundaries and unit names are abbreviated from figure 2-3.

the diverse named stratigraphic units that have appeared on regional, local, and partial columns and charts over many years. These units can be coordinated consistently, as shown in figure 2-3, which can be compared and contrasted with the similar but nonduplicative charts in Hay (paper 17 in this volume), Holland (paper 18), and Schumacher (paper 16), as well as with earlier comprehensive portrayals (figs. 2-6 and 2-7).

Most of the type-Cincinnatian formations and members are characterized by one or another of the facies groups noted earlier (fig. 2-2). Thus, their paleoecologic implications can be plotted for the entire type-Cincinnatian (fig. 2-4), so that one easily can see the fluctuating mosaic of paleoenvironments that produced this complicated set of deposits.

One can derive additional relevant information from figure 2-4. Moving horizontally across the chart permits construction of a regional profile or cross section of the adjacent paleoenvironments existing across the Cincinnati region at a given moment in time, as for example at the time when the Maysville bryozoan reef mounds were growing (see Cuffey, paper 5 in this volume, fig. 5-3). Moving vertically up the chart enables construction of a depth curve for a given location within the region (fig. 2-5); it is interesting to note that the same major shallowing-upward cycles are evident in the papers by Hay, by Holland, and by Schumacher in this volume (papers 17, 18, and 16, respectively).

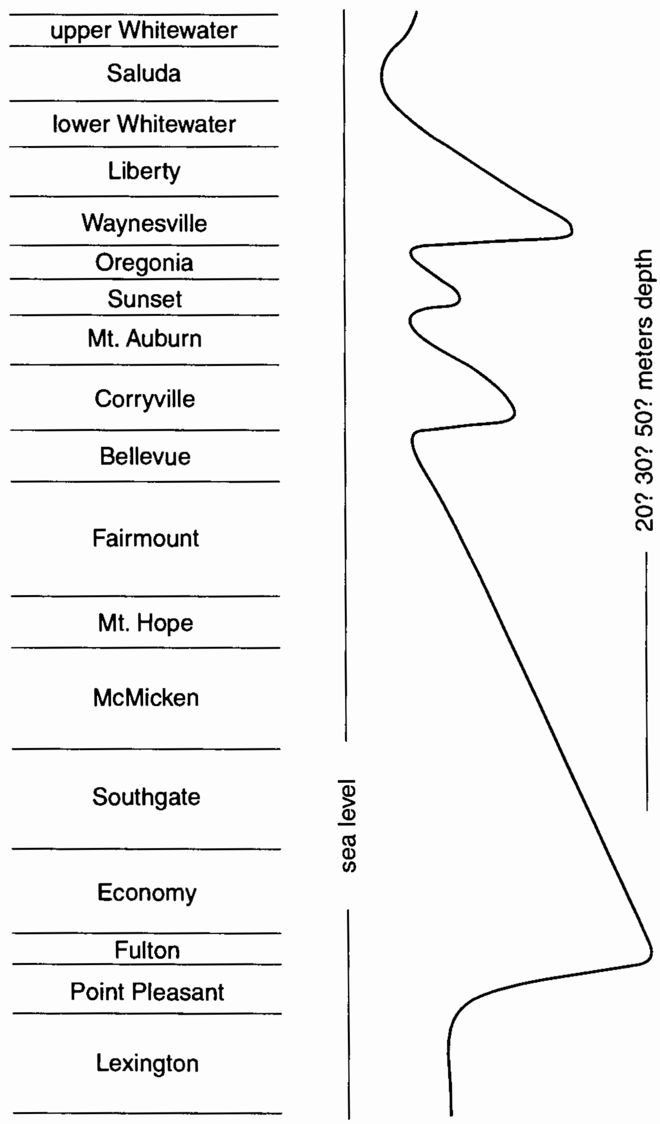


FIGURE 2-5.—Depth curve for the area between Cincinnati, Madison, and Richmond, inferred from the succession shown in figure 2-4 and using paleoenvironments appearing in figure 2-2.

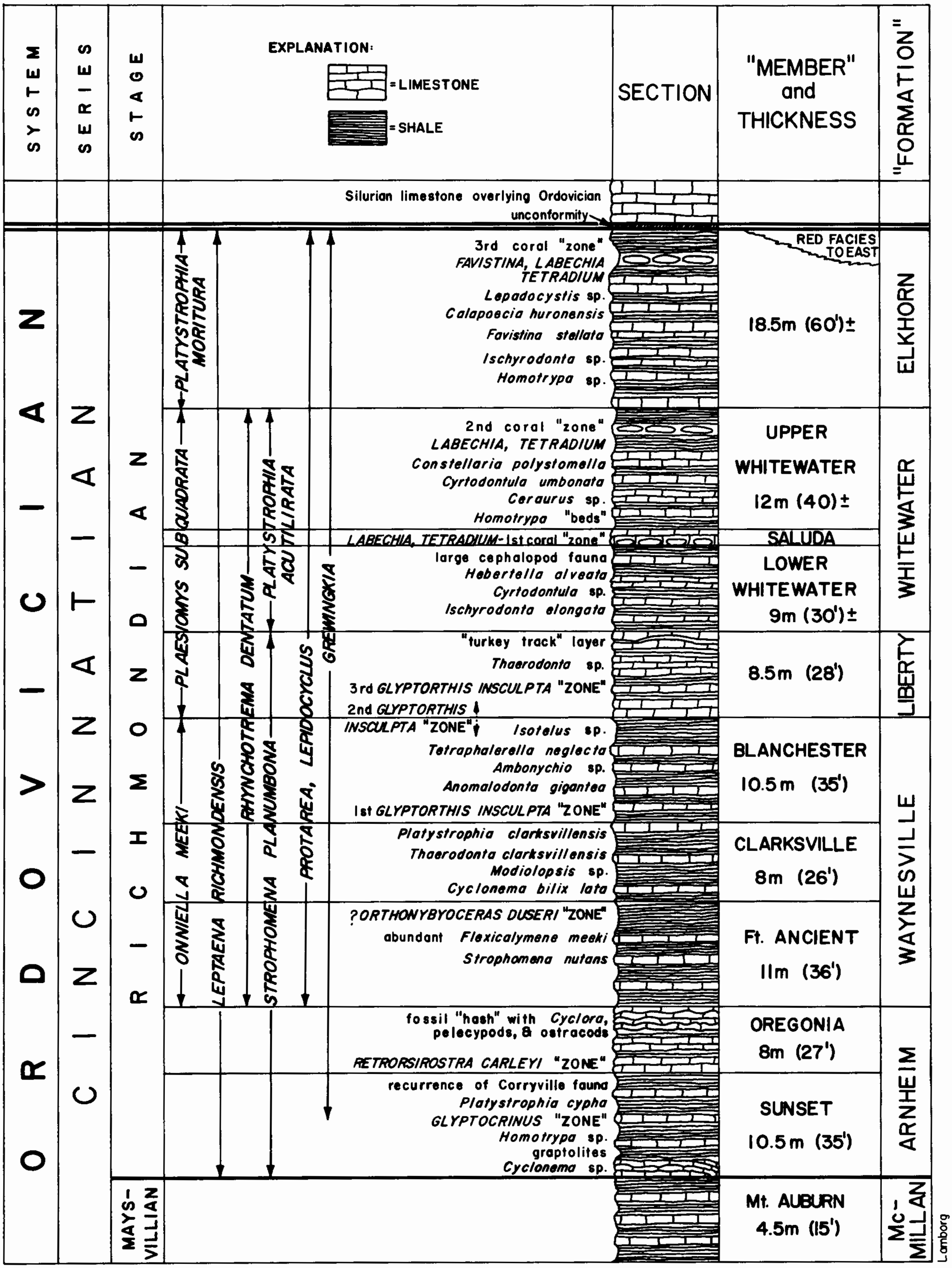
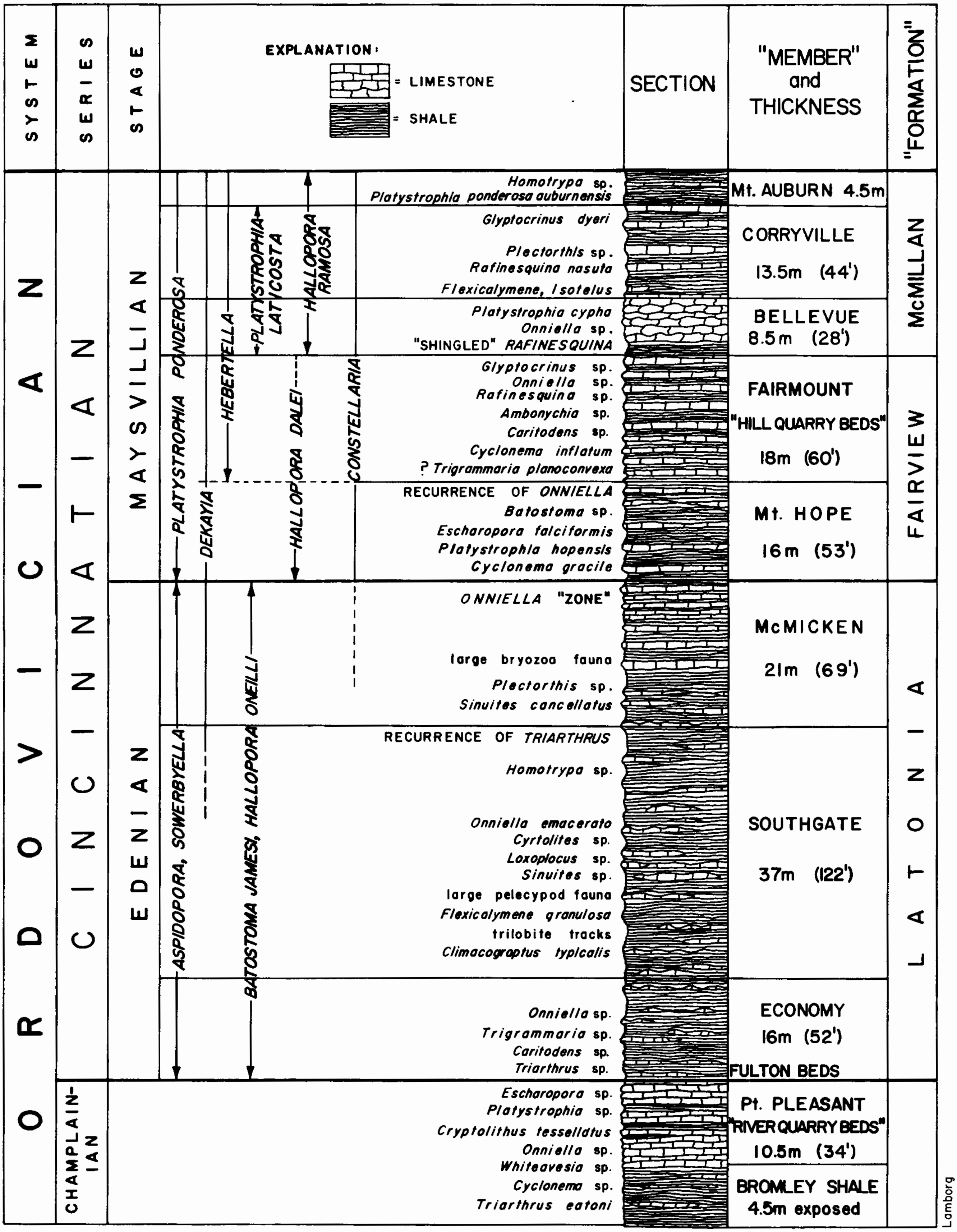


FIGURE 2-6.—Stratigraphic units and fossil ranges for Edenian, Maysvillian, and Richmondian strata



at and near Cincinnati (from Davis, 1992, p. 21-22; revised from Caster, Dalvé, and Pope, 1955, p. 12-13).

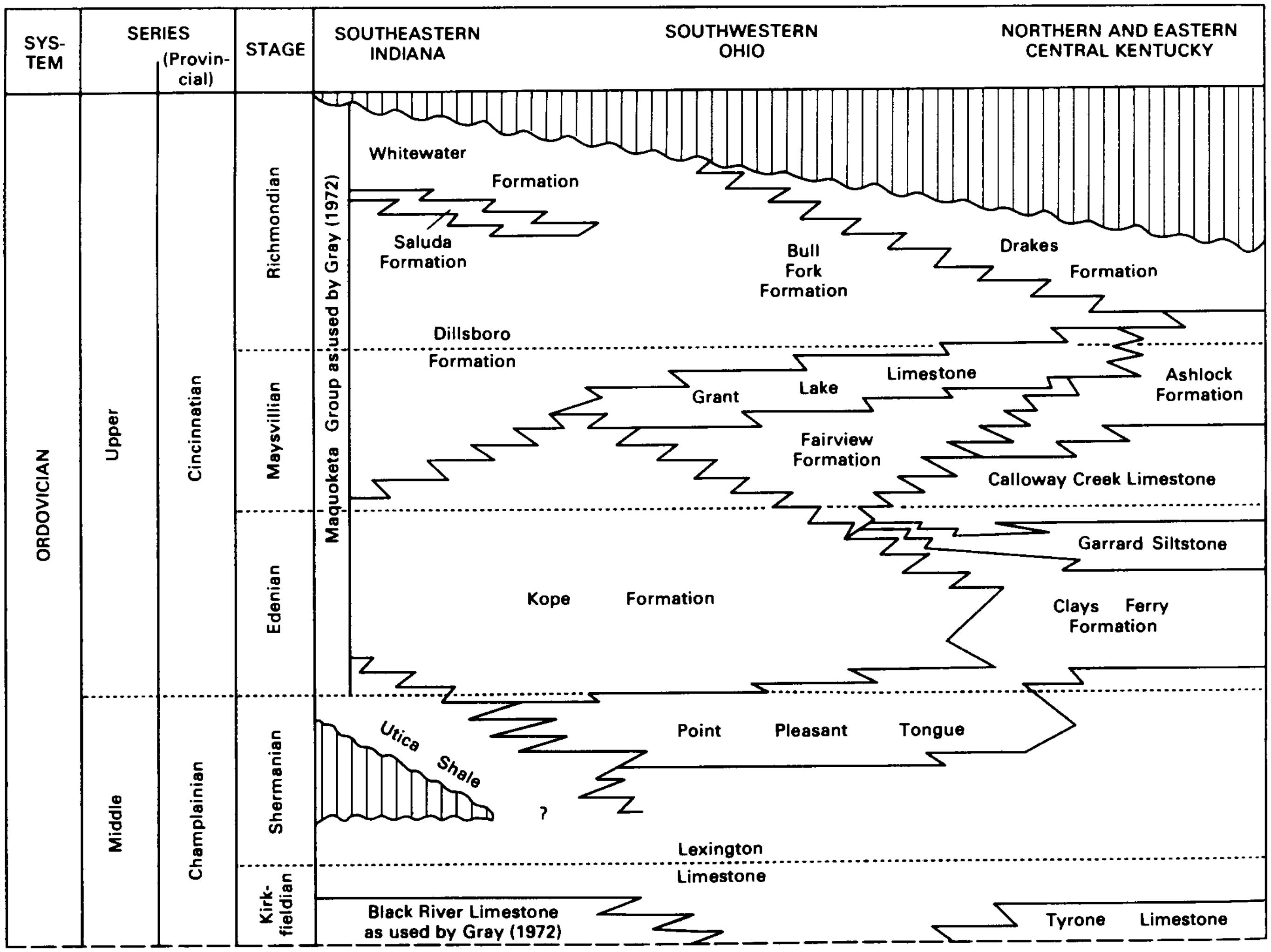


FIGURE 2-7.—Stratigraphic relationships of principal type-Cincinnatian lithostratigraphic units as determined from conodont biostratigraphy (from Pojeta, 1984, p. 80; modified from Sweet, 1979, p. 13).

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Address of author: Roger J. Cuffey, Department of Geosciences (Deike Bldg.), Pennsylvania State University, University Park, PA 16802.

3. KOPE TO BELLEVUE FORMATIONS: THE RIEDLIN ROAD/MASON ROAD SITE (UPPER ORDOVICIAN, CINCINNATI, OHIO, REGION)

by
Sharon C. St. Louis Diekmeyer

SIGNIFICANCE

The Riedlin Road/Mason Road site (fig. 3-1) provides a well-exposed sequence of strata including the upper Kope, Fairview, and Bellevue Formations and at least two intervals of the Miamitown Shale facies (fig. 3-2). This road cut allows easy and safe access to all the formations present. Many recent studies have used this section for these reasons (Tobin, 1982; Jennette, 1986; Diekmeyer, 1990; Holland, 1990, 1993).

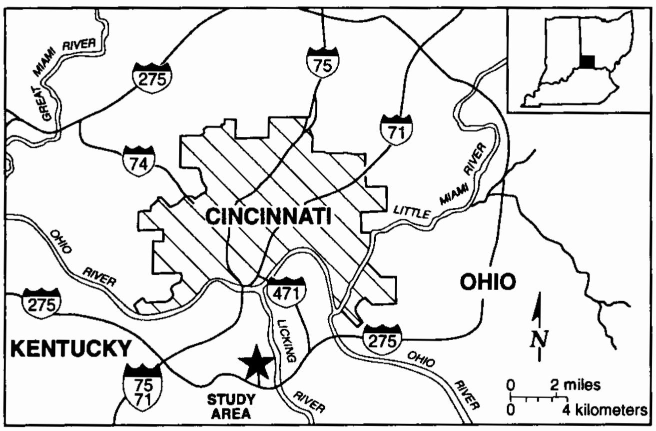


FIGURE 3-1.—Location of the Riedlin Road/Mason Road site (KY-KE-0001) (modified from Jennette, 1986).

LOCATION

This site (KY-KE-0001) is located in Kenton County, Kentucky, at the intersection of Kentucky Route 16 (Taylor Mill Road) and Riedlin Road/Mason Road, 0.4 mile (0.6 km) north of I-275 (Exit 79), at 39°01'40"N latitude, 84°30'38"W longitude on the Covington, Kentucky–Ohio, 7.5-minute quadrangle (Ford, 1974; Luft, 1971).

TYPE SECTIONS

The abundant exposures of fossiliferous strata in the Cincinnati area have provided opportunity for intense study since before the middle of the 19th century, when these rocks were called the "Blue Limestone" (Locke, 1838; Hall, 1842). The first designation of these beds as the Cincinnati Group (Meek and Worthen, 1865) referred to strata bounded below by the Trenton Limestone and above by the Silurian formations (Orton, 1873). This group was divided on the basis of stratigraphic position (Orton, 1873). These divisions included, in ascending order, the Point Pleasant Beds, the Cincinnati Beds, and the Lebanon Beds. The Cincinnati Beds, in turn, were subdivided stratigraphically into the River Quarry Beds, the Middle or Eden Shales, and the Hill Quarry Beds (on the top), on the basis of lithologic and faunal characteristics. Typical fossils from the Riedlin Road/Mason Road locality are illustrated in figures 3-16, 3-17, and 3-18 at the end of this paper.

KOPE FORMATION

The Eden Shales were named for 250 ft (76.2 meters) of blue clay and limestone interbeds (limestone-to-clay ratio 1:10; Orton, 1873) exposed in Eden Park in Cincinnati (fig. 3-3; this outcrop no longer is accessible because of development). Nickles (1902) used the term Utica Group for the Middle Shales on the basis of James Hall's (1842) correlation with the Utica Shales of New York and divided these shales using lithologic and faunal variations. These beds were termed the "Lower Utica or *Aspidopora newberryi* Beds" (about 80 ft/24 meters of greenish-gray, drab, or yellowish shales, more indurated than those occurring stratigraphically higher), the "Middle Utica or *Batostoma jamesi* Beds" (about 120 ft/36 meters of rather unfossiliferous strata with less limestone than the other two units), and the "Upper Utica or *Dekayella ulrichi* Beds" (about 60 ft/18 meters of more fossil-rich shales with increased abundance of thin, slabby limestones). Bassler (1906), in turn, gave these members local geographic names—Economy, Southgate, and McMicken, respectively. Foerste (1905) named the lowermost dark-shale zone containing abundant specimens of the trilobite *Triarthrus eatoni* the "Fulton Beds." Weiss and others (1965) concluded that all these divisions were based upon bryozoan zones found at Cincinnati and were not useful in subdividing the Eden Formation in areas adjacent to the Cincinnati area. On the basis of clastic ratio and bedding logs, Weiss and Sweet (1964) correlated Eden-like strata in the Maysville area of Ohio and Kentucky with the Eden (Edenian) and Mt. Hope (Maysvillian) Formations at Cincinnati. Because of confusion brought on by the usage of Eden for both a stage and a rock unit, especially in reference to a section where the rock unit transgressed the Edenian-Maysvillian boundary, the rock-unit name Kope Formation was proposed by Weiss and Sweet (1964) to include those strata falling between the Point Pleasant limestones and beds having a clastic ratio of 2.5 to 3.8 that they didn't name but correlated with the Fairview Formation of the Cincinnati area. The name Kope was derived from Kope Hollow, in Brown County, Ohio, nearly 50 miles (75 km) to the southeast (fig. 3-4). There is no one complete section known. However, Weiss and Sweet (1964) established a composite section thickness of 73.5 meters (241 ft). Kope Hollow, Ohio (OH-BR-0003), Red Oak Creek, Ohio (OH-BR-0004), and Maysville, Kentucky (KY-MS-0004), were designated co-equal Kope type sections.

FAIRVIEW FORMATION

Orton (1873) named the Hill Quarry Beds for 125 ft (38.1 meters) of strata lying between the Eden Shales and the Lebanon Beds. These beds provided abundant limestone for building and for lime production. The Hill Quarry Beds make up the tops of the hills around the downtown Cincinnati area. Orton (1873) defined the contact with the underlying Eden Shales on the basis of the increase in the limestone-to-clay ratio (1:5 or 1:6). Winchell and Ulrich (1897) proposed the name Lorraine Group in their correlation of fauna

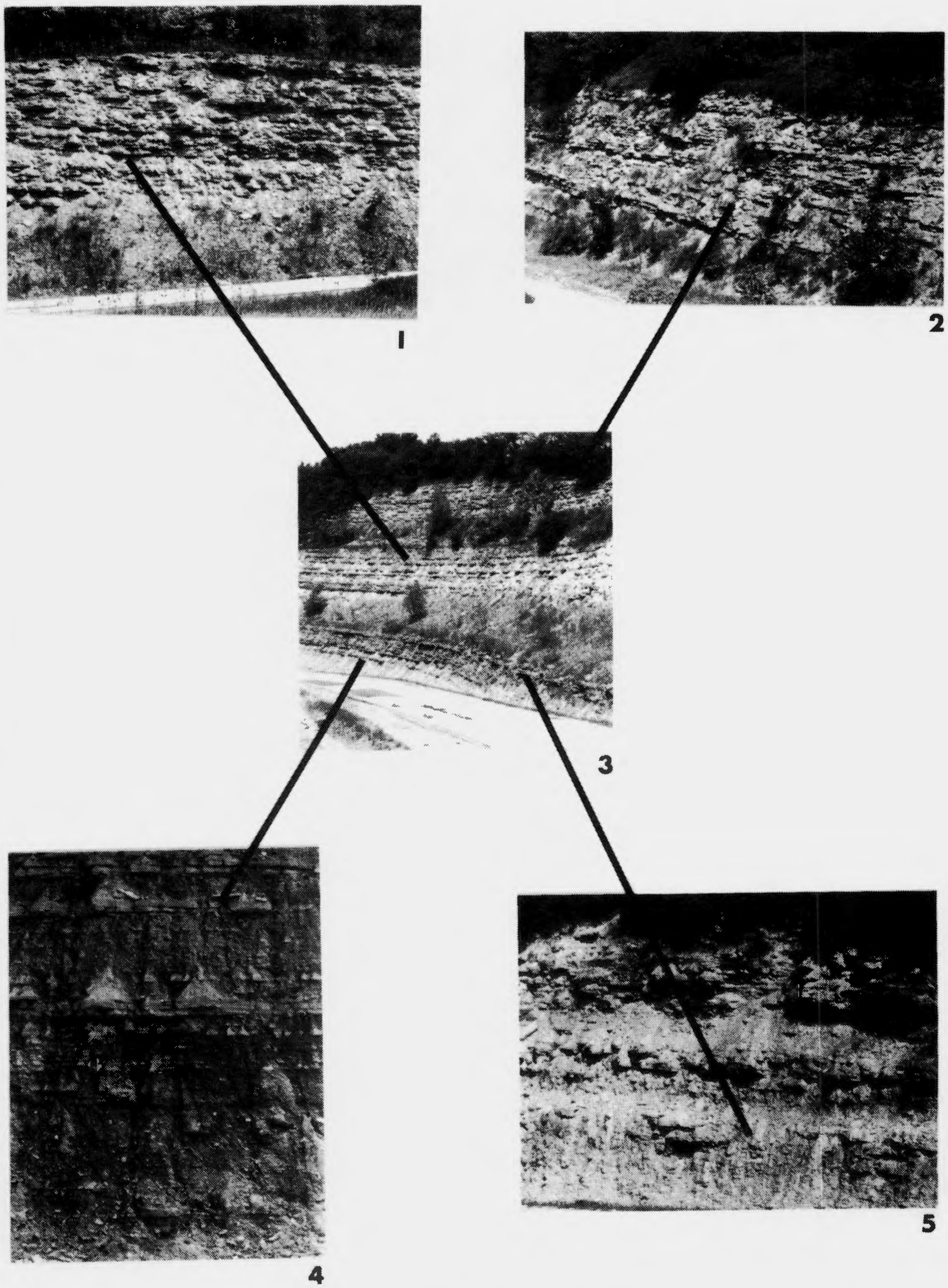


FIGURE 3-2.—Riedlin Road/Mason Road locality. Center photo (**3**) is a small-scale view of most of the section exposed at the locality; photographs 1, 2, 4, and 5 are keyed to it. **1**, upper part of the Fairview Formation. **2**, Miamitown Shale/Bellevue interval. **4**, top three cycles in the upper part of the Kope Formation; the limestone bed indicated is just below the "two foot shale" that underlies the Kope-Fairview contact. **5**, three cycles in the lower part of the Fairview Formation.

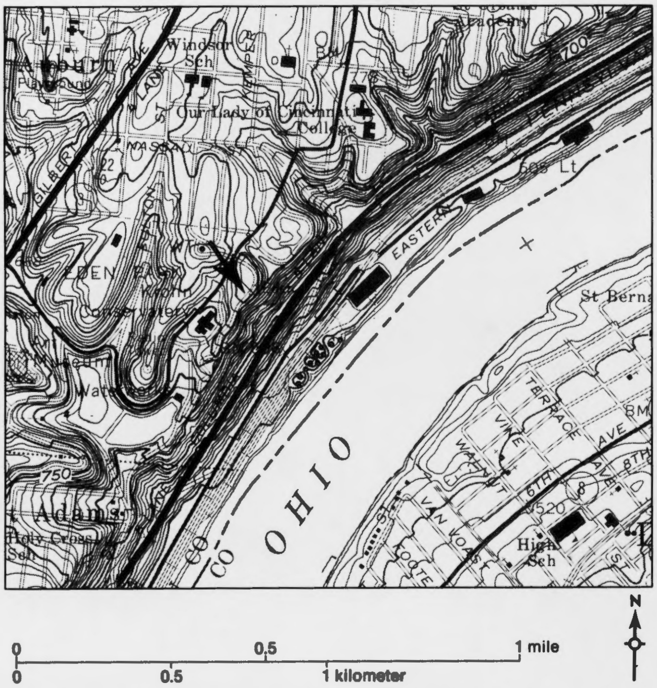


FIGURE 3-3.—Location of Eden Park, for which the Eden Shales were named. The arrow indicates the approximate location of the original type section of the Eden Shales. Newport, Kentucky–Ohio, 7.5-minute quadrangle.

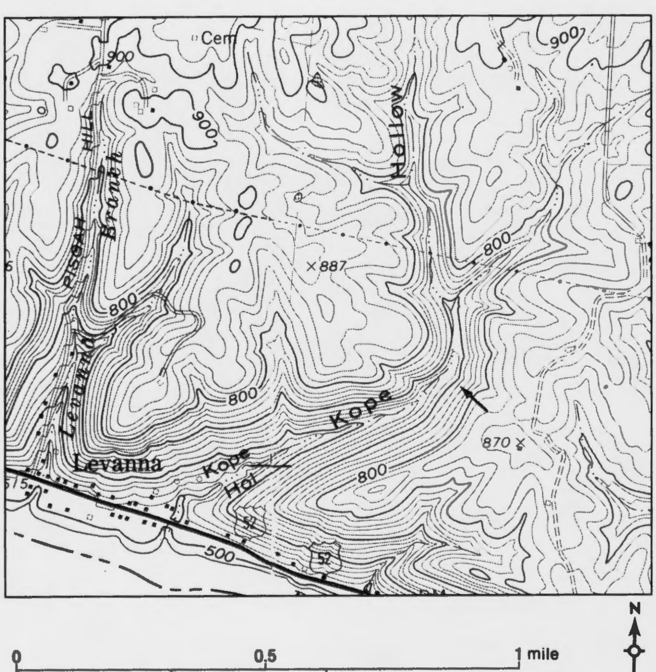


FIGURE 3-4.—Location of Kope Hollow (OH-BR-0003), for which the Kope Formation was named. The position of the most obvious exposure is indicated by the arrow. Russellville, Ohio–Kentucky, 7.5-minute quadrangle.

from the Illinois area. Nickles (1902) divided the Lorraine Group into six intervals on the basis of faunal and lithologic character. These included, from bottom to top: the "Mt. Hope or *Amplexopora septosa* Beds," the "Fairmount or *Dekayia aspera* Beds," the "Bellevue or *Monticulipora molesta* Beds," the "Corryville or *Chiloporella nicholsoni* Beds," the "Mt. Auburn or *Platystrophia lynx* Beds," and the "Warren or *Homotrypa bassleri* Beds."

Mt. Hope beds

The Mt. Hope beds were thought to range between the "heavy, irregularly bedded limestones" containing abundant *Dalmanella multisecta* above the Utica Shale and the *Strophomena planoconvexa* zone (Nickles, 1902, p. 76). The type exposure was designated as the southeastern portion of Price Hill known as Mt. Hope (fig. 3-5).

Fairmount beds

The Fairmount beds consist of that portion of the Lorraine known as the Stone Quarries or Hill Quarry Beds of Orton (1873). Nickles (1902) proposed the name Fairmount, because all the hilltops in the Fairmount area (north of Price Hill and south or southwest of Cumminsville and west of Mill Creek) exhibited these beds (fig. 3-5). Nickles (1902) determined that these strata also occupied the hilltops around Covington and Newport, Kentucky. Bassler (1906) lumped the Mt. Hope and Fairmount beds into the Fairview Formation because of the difficulty in discerning faunal differences and mapping the units. Bassler (1906) named the Fairview for about 100 ft (30 meters) of strata at Fairview Heights, Cincinnati (OH-HA-0001). Ford (1965, 1967) redefined the Fairview Formation as a rock-stratigraphic unit and designated the south- and west-facing cliff below Bellevue Hill Park along Clifton Avenue (OH-HA-0003) as the type section (fig. 3-5). The boundaries of the Fairview were based on a mean clastic content of 64 percent and bedding-index characteristics (Ford, 1967).

BELLEVUE FORMATION

Nickles (1902) distinguished the "Bellevue or *Monticulipora molesta* Beds" as the 15 ft (4.6 meters) of strata exposed at the top of the cliff below the site of the old Bellevue House (OH-HA-0003). Lithologically, these beds exhibit a shelly appearance and contain abundant bryozoans. *Monticulipora molesta* was considered one of the most characteristic bryozoan species of these strata. At the top of the Bellevue, Nickles (1902) noted about 5 ft (1.5 meters) of section containing abundant specimens of what he called *Rafinesquina alternata*. Bassler (1906) chose to incorporate the Bellevue, Corryville, and Mt. Auburn beds of Nickles (1902) into the McMillan Formation, thus reducing them to member status. He felt these members were closely related and "not of sufficient status to be mapped separately" (Bassler, 1906, p. 10). He chose McMillan Avenue in the Clifton portion of Cincinnati as the type section for this formation. Peck (1966), however, considered the boundaries to be poorly defined, and he rejected the McMillan Formation and its three members as rock-stratigraphic units. Using lithologic characteristics, Peck (1966) assigned rocks in the Maysville, Kentucky, area that previously had been referred to the McMillan Formation to the Grant Lake Limestone.

FIGURE 3-5.—Locations of several sites within the type-Cincinnatian. Covington, Kentucky–Ohio, Cincinnati West, Ohio, and Newport, Kentucky–Ohio, 7.5-minute quadrangles. **BH** = Bellevue Hill (OH-HA-0003), **BK** = Bald Knob (OH-HA-0013), **CHS** = Rice and Gage Streets/Christ Hospital (OH-HA-0004), **EMG** = Emming Street (OH-HA-0002), **FM** = Fairmount section of Cincinnati, **FV** = Fairview Park (OH-HA-0001), **JH** = Jackson Hill (OH-HA-0018), **MH** = Mt. Hope, **MM** = McMillan Street (OH-HA-0027).

He designated road cuts along Kentucky Route 1449 about 6.5 km (4.0 miles) north-northwest of Orangeburg, in Mason County, Kentucky (Sleepy Hollow, KY-MS-0005), as the type section. Previously, other workers had correlated the beds of the Grant Lake Limestone with the McMillan Formation in the Cincinnati area (Palmquist and Hall, 1960; McFarlan and Nosow, 1961; Carpenter and Ory, 1961). Ford (1967) formally defined the Bellevue Limestone as a rock unit based on lithologic character and designated the type section as the cliff at the intersection of Rice and Gage Streets, Cincinnati (OH-HA-0004; fig. 3-5). He suggested that the Bellevue Limestone may represent a northwesterly tongue of the Grant Lake Formation of Peck (1966). Tobin (1982) compared the Grant Lake Limestone and the Bellevue Limestone and found the rock types, fauna, bedding character, and shale content of the two to be similar.

MIAMITOWN SHALE

Many early workers noted the presence of a shaly interval containing abundant molluscan remains associated with the Bellevue Limestone. Ford (1967) proposed the name Miamitown Shale to denote the thin shale unit that overlies the Fairview Formation. He noted that it is lithologically and faunally different from the surrounding strata and designated the highway cut along Interstate 74, 1.6 km (1 mile) west of Miamitown as the type section (OH-HA-0008). Please see Dattilo (paper 7 in this volume) for details on the historical development of the Miamitown Shale.

DESCRIPTIVE STRATIGRAPHY

Previous lithostratigraphic studies of the Cincinnatian exhibit a diversity of opinions on the placement of boundaries and the criteria useful for separating units. Many authors stated that original unit boundaries were based solely on faunal zones (Cumings, 1922; Gutstadt, 1958; Brown and Lineback, 1966). Assessment of the original literature by others (Weiss, 1961; Krumpolz, 1980; Tobin, 1982, 1986) drew attention to the use of both lithologic and faunal character for distinguishing unit boundaries. Tobin (1982, 1986) revised the lithostratigraphy of the Cincinnatian, basing his scheme on the original unit descriptions and the recognition of sequences of related facies within each unit. This approach opened the way for study of the variability of units on a wider geographic scale and reduced the parochialism of geographically isolated studies. Lithologic designations used in this paper follow the classification of Dunham (1962), as modified by Tobin (1982).

KOPE FORMATION

The Riedlin Road/Mason Road outcrop exposes the upper 8.5 meters (27.9 ft) of the Kope Formation. This sequence contains medium-bedded, generally unfossiliferous, blue-gray calcareous (locally silty) shales. These shales are interbedded with medium (3-4 cm) calcisiltites, thin, lenticular (1-2 cm) skeletal packstone/wackestone beds, and medium (less than 8 cm) to thick (more than 8 cm) planar skeletal packstone/grainstone beds. Many of the thick packstone/grainstone beds are laterally continuous and have been traced across the Cincinnati area (Jennette, 1986). The shale component makes up 75-80 percent of the unit's total thickness (shale interval thicknesses of approximately 1 meter). There is a general increase in the number and thickness of the packstone/wackestone beds approaching the top of the formation. Sedimentary features noted in Kope strata include symmetrical and asymmetrical ripples, starved ripples, planar lamination and cross-lamination, tool marks, flute casts, gutter casts, load structures, and ball-and-pillow structures (Tobin, 1982). Ford (1967, p. 929) originally defined the Kope/Fairview contact as the base of the limestone bed above the "...uppermost terrigenous stratum greater than 2 feet thick." Tobin (1982) interpreted the terrigenous stratum to be the shale bed, and this interval has come to be termed the "two foot shale" that is readily observable throughout the Cincinnati area. Alternatively, Jennette (1986) placed the contact at the top of the limestone bed above this shale unit; this was done on the basis of a different depositional interpretation of the facies packages (refer to paleoenvironmental interpretation section).

FAIRVIEW FORMATION

Ford (1967) originally defined the Fairview Formation as interbedded limestones, siltstones, and shales with bedding thicknesses of generally less than 0.6 ft (0.2 meter). His emphasis on the "close spacing" of the limestone beds indicates the trend toward decreased shale occurring in thinner beds than those of the underlying Kope Formation (Tobin, 1982). At the Riedlin Road/Mason Road site the entire Fairview Formation is exposed. The 31.7 meters (104 ft) of section is approximately 50 percent planar to lenticular, gray to blue-gray, skeletal limestone beds. These limestones are generally packstones to grainstones with fewer wackestones (although wackestone lenses occur within and around thicker packstone/grainstone beds). Grainstones are more abundant than in the underlying Kope strata. Compound beds containing both a packstone or wackestone component and a grainstone component are common. Limestone beds commonly are blanketed with a thin (1-2 mm) to medium (1-2 cm) bioturbated silt layer. Calcareous, silty shales and calcareous siltstones constitute the remaining beds in this interval. The lower half of the Fairview Formation contains about 55 percent shale, whereas the upper half contains 45 percent (Tobin, 1982). Shales are generally less silty than those of the Kope beds.

The upper contact of the Fairview originally was defined by Ford (1967) as the top of the limestone bed that occurs below a shale unit that is more than 0.6 meter (2 ft) thick and exhibits a very different lithology (Miamitown Shale). Imbricated (shingled) brachiopods occur in several beds toward the top of the Fairview Formation. Many workers have used the "shingled *Rafinesquina* zone" of Caster, Dalvé, and Pope (1955) as the boundary. However, there is much controversy regarding the regional extent of this "zone." The problem with this contact is the intertonguing nature of the Fairview, Miamitown Shale, and the Bellevue beds (see Dattilo, paper 7 in this volume). Tobin (1982) redefined the top of the Fairview Formation as the top of the uppermost planar, medium-bedded limestones and shales. Either the shale-rich, nodular Miamitown facies or the wavy-bedded, limestone-dominated Bellevue beds may occur above this contact. Designating a contact at the Riedlin Road/Mason Road site is difficult. However, the contact probably exhibits an intertonguing between the Fairview beds and a Miamitown interval (see below).

MIAMITOWN SHALE

The Miamitown Shale contains shales interbedded with thin- to medium-bedded limestone lenses and beds and abundant limestone nodules (Tobin, 1982). This unit thickens north-northwestward from 0.4 meter (1.3 ft) in northern Kentucky to more than 5 meters (16.4 ft) at the type section (Miamitown West, OH-HA-0008). At Riedlin Road/Mason Road there appear to be two intervals of Miamitown Shale lithology. The first occurs above the Fairview Formation boundary, is about 0.5 meter (1.6 ft) thick, and has abundant siltstone layers. This corresponds temporally to the Miamitown Shale exposed at the type section (OH-HA-0008). The 0.4-meter (1.3-ft)-thick second interval is about 2.5 meters (8.2 ft) above the "upper shingled *Rafinesquina* zone." It contains an average of 76 percent shale, less silty than underlying shales (Tobin, 1982). The dominant limestone types are packstones, wackestones, and micstones (Tobin, 1982). Sedimentary structures include gutter casts and cross-lamination. The limestone nodules exhibit ovoid and ripple shapes, are not more than 15 cm (4 inches) in length, and commonly occur along discrete horizons. These nodules commonly are cross-laminated internally. The relationship of the Miamitown Shale facies to the Bellevue and Fairview Formations is discussed in depth by Dattilo (paper 7 in this volume).

BELLEVUE FORMATION

The Bellevue interval at Riedlin Road/Mason Road is characteristic of exposures in the Cincinnati area. It consists of irregularly bedded, gray, argillaceous limestones (70-90 percent, Tobin, 1982) composed of whole and broken brachiopod valves and bryozoan colonies. The rubbly or "crenulated" appearance of the beds results from the weathering of thin, shale partings and the convexity and concavity of the brachiopod valves (Ford, 1965, 1967). Many beds are not laterally traceable for more than a few meters, although some thicker beds may be followed along the length of the outcrop. Beds range from poorly sorted to well-sorted packstones and grainstones. Thin beds and partings of gray, calcareous shales contain more abundant fossil material than do underlying beds. Fining-upward and some coarsening-upward sequences are common within beds. Discrete horizons of fossils and fossil fragments within beds exhibit planar to indistinguishable orientation trends. The bases of beds commonly are composed of abundant concave-down brachiopod valves. Mud sheltering beneath valves and spar filling of brachiopods and bryozoan colonies are characteristic features. Mud within and surrounding valves and fragments may be pelletal. Increased size and robustness of faunal elements, dominated by brachiopods and bryozoans, characterize this interval. These fossils exhibit varying degrees of breakage, encrustation, boring, and corrasion. Encrusting bryozoans are much more abundant than in the Fairview or Kope Formations. Many bryozoan colonies are preserved as phosphatic internal molds of zooecia. There is also increased preservation of pelecypod internal molds and body fossils.

Because of the difficulty in finding exposures of the top of the Bellevue strata, Ford (1965, 1967) designated the contact as a gradational "zone" between the uppermost Bellevue "coquinite limestone" and the "overlying weak shale and thin-bedded limestone" (Ford, 1967, p. 934) of his "unnamed beds." Tobin (1982) determined that this contact was not gradational but was the "sharp termination of thin, wavy-bedded, shale-poor strata characteristic of the Bellevue Limestone, and the beginning of the thicker, planar-bedded limestones and shales of the Corryville Formation" (Tobin, 1982, p. 166). Although not exposed at Riedlin Road/Mason Road, the Bellevue/Corryville contact in other outcrops is sharp to gradational (see Goldman, paper 8 in this volume).

PALEOENVIRONMENTAL INTERPRETATION

The local Cincinnatian is characterized by alternating beds of relatively unfossiliferous shales and fossil-rich limestones. Many researchers have tried to explain the origin of this characteristic arrangement of strata. Bucher (1917) was the first worker to ascribe this pattern to the introduction of storm-derived shelly accumulations onto normal mud sedimentation. For many years, researchers proposed depositional models that depended on variations within the depositional system (autocyclic mechanisms). These models included variability in water temperature or rate of sediment supply (Fox, 1962). Weiss and others (1965) and Osborne (1971) suggested a model of shifting silt-dispersal systems that allowed blanketing of benthic communities on submarine highs, producing autochthonous, skeletal accumulations. Shifting sediments exposed other areas for colonization.

STORM-DOMINATED SYSTEMS

Over the past 25 years, storm events have been singled out as a predominant influence on Cincinnatian depositional patterns. Anstey and Fowler (1969) interpreted the depositional pattern of the Eden Shale (now designated the Kope Formation) to be the result of an environment of quiet mud sedimentation interrupted by periodic storms that deposited winnowed, coarse shell lags. Harris and Martin (1979) suggested colonization of muddy substrates by flat-valved brachiopods as the initial stage in short-term faunal succession within the Cincinnatian limestone beds. Increased stabilization of the substrate by brachiopods allowed colonization by trepostome bryozoans and, subsequently, by crinoids, trilobites, gastropods, and pelecypods. Storm-induced influx of terrigenous material smothered the community and provided a muddy substrate for inception of a new successional cycle. Examination of the limestone beds within the Kope Formation led Harrison and Mahan (*in* Meyer and others, 1981) to conclude that, commonly, only partial successional sequences were evident. The occurrences of sequences that originated after the pioneer stage indicate that postdepositional transport of shelly debris may have been responsible for second-generation successional communities. Modification of the substrate by accumulation of skeletal debris and the influence this has on community structure (taphonomic feedback) has been studied recently in relation to storm-dominated systems (Kidwell and Jablonski, 1983; Kidwell, 1986b; Kidwell and others, 1986). Tobin (1982) noted the arrangement of Kope through Bellevue strata into limestone-shale couplets. Resuspension of offshore muds by periodic storms and redeposition onto nearshore carbonates by waning storm conditions was the model used to explain these couplets.

PALEOGEOGRAPHIC INTERPRETATION

Recent studies of Late Ordovician paleogeography locate the Cincinnati region between 15° and 25° south latitude and rotated 45° clockwise of present-day orientation (Kriesa, 1981a; Tobin, 1982; Weir and others, 1984; Jennette, 1986; Jennette and Pryor, 1993). Many researchers have inferred a northward-dipping ramp during this time (Weiss and others, 1965; Hoffman, 1966; Ford, 1967; Anstey and Fowler, 1969; Hay, 1981; Weir and others, 1984). Reconstructed ancient oceanic- and wind-circulation patterns indicate a storm track moving toward the south-southwest and impinging on the ramp (Ziegler, 1981; Tobin, 1982) (fig. 3-6). Idealized storm sequences from the Middle and Upper Ordovician Martinsburg and Reedsville Formations on the eastern margin of the Appalachian Basin (Kriesa, 1981a) are comparable to the patterns found in Cincinnatian depositional sequences (Tobin, 1982).

STORM-DEPOSITIONAL MODEL

Many recent studies of storm-dominated systems on modern and ancient shelves use a proximal-distal model to explain the depositional patterns noted (Kreisa, 1981a, 1981b; Brett, 1983; Aigner, 1985). This model has been used to explain the sequences found within the Kope-Fairview interval (Jennette, 1986; Jennette and Pryor, 1993). Hurricanes or winter storms moved toward the south-southwest across the adjacent ocean and intersected the north-northwestward-sloping ramp perpendicularly or at a high angle to the shoreline. Offshore winds set up a gradient onshore that resulted in an associated offshore storm surge with enough velocity to entrain abundant terrigenous and bioclastic material on the ramp (fig. 3-7). The storm surge, moving beneath the onshore-trending currents, carried the coarser material offshore, depositing sorted skeletal material below fair-weather wave base. In turn, waning storm conditions carried finer grained material and deposited it farther down ramp (distal tempestites). Renewed sedimentation below fair-weather wave base resulted in mud accumulations blanketing shell lags and tempestites (fig. 3-7).

MEGACYCLES

Tobin and Pryor (*in* Meyer and others, 1981) and Tobin (1982) noted the arrangement of beds into repeating vertical sequences within the Kope-through-Bellevue interval. These megacycles are represented by a basal, limestone-rich hemicycle composed of grainstones, packstones, wackestones, and calcisiltites interbedded with shales and a capping, shale-rich hemicycle containing interbedded thin

FIGURE 3-6.—Paleogeographic reconstruction showing the location of the study area during the Late Ordovician, 438 million years ago. Arrows indicate the inferred paths of hurricanes and severe storms as they approached the Cincinnatian ramp (modified from Scotese and Denham, 1988).

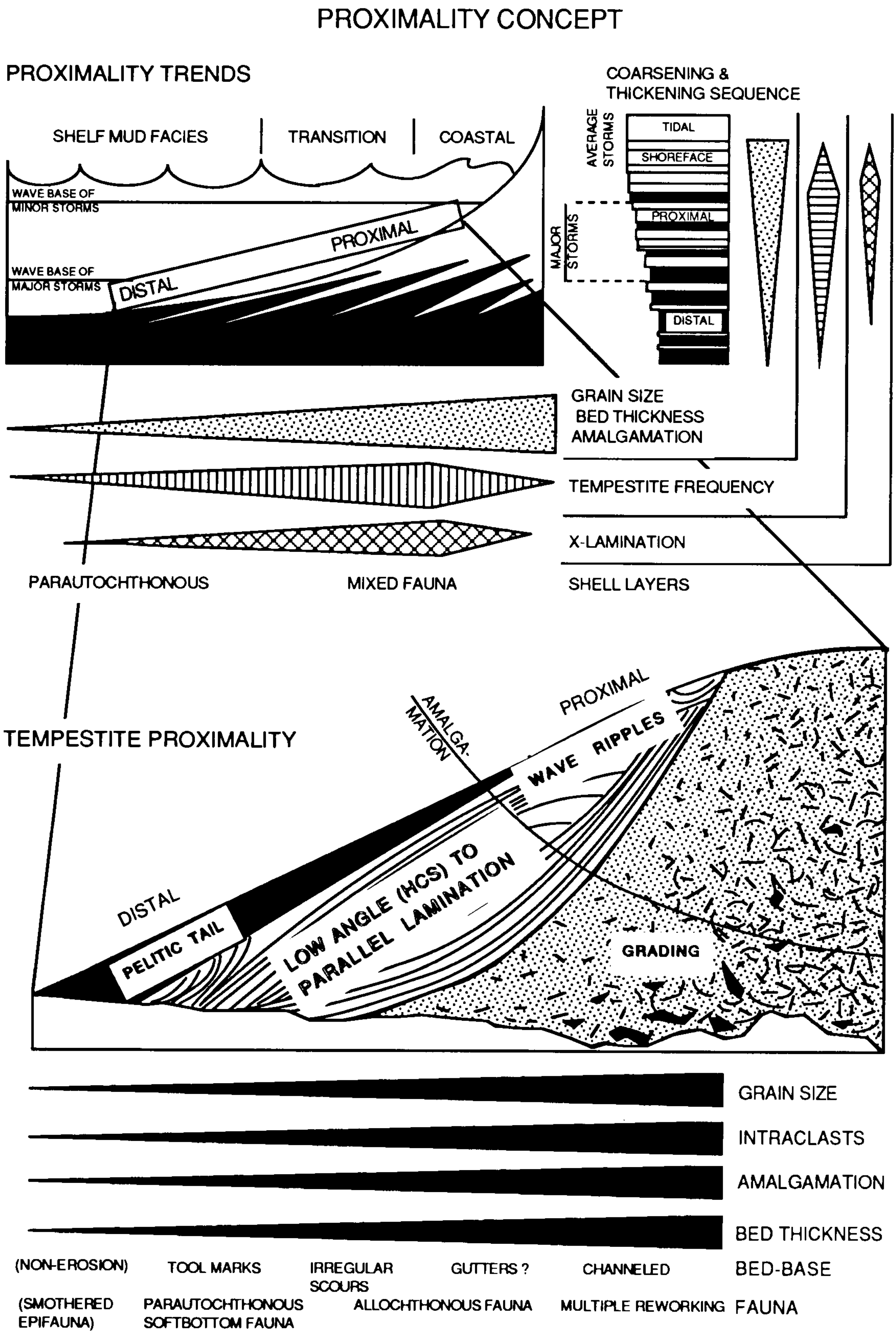


FIGURE 3-7.—Proximal-distal storm model showing the resultant lateral and vertical distribution of facies (from Aigner, 1985b).

carbonate beds (Meyer and others, 1981; Tobin, 1982). Changes in supply of terrigenous sediment resulting from delta switching, lateral changes in sediment supply, or tectonic and/or volcanic activity were suggested as possible explanations for these megacycles. Jennette (1986) and Jennette and Pryor (1993) re-interpreted these cycles as shallowing sequences, because the shale hemicycles appear to coarsen rather than fine upward, and the carbonate component exhibits thickening beds toward the top of each megacycle. The shale hemicycle represents offshore deposition that aggraded, shifting proximal deposition basinward. Thin carbonate beds within the shale component represent influxes of nearshore material during storm-surge activity. The capping, amalgamated grainstones (proximal tempestites) resulted from winnowing of previously deposited shell accumulations nearshore. Deposition of shales directly atop capping, amalgamated grainstones is thought to have resulted from a relatively rapid transgressive pulse related to glacio-eustatic sea-level rise (Jennette, 1986; Jennette and Pryor, 1993) (fig. 3-8). This asymmetrical regressive-transgressive pattern has been noted in other studies at a similar scale (Goodwin and Anderson, 1980; Aigner, 1982, 1985; Bayer and others, 1985; Einsele, 1985; Brett and others, 1986b).

LARGE-SCALE, SHOALING-UPWARD CYCLES

Three packages of thinning shale hemicycles and thickening limestone hemicycles were noted in the Cincinnatian by Tobin and Pryor (*in* Meyer and others, 1981) and Tobin (1982); they interpreted these to be large-scale regressions. Holland (paper 18 in this volume) notes the presence of four shallowing-upward cycles. The Kope-through-Bellevue sequence is the first of these regressions. Location of individual megacycles within this large-scale shoaling sequence determines their character (fig. 3-9). Megacycles within the deeper water Kope Formation exhibit thick shale intervals (approximately 1 meter) that have thick amalgamated limestones restricted to the top of each cycle. Four megacycles can be delineated in the Kope Formation at the Riedlin Road/Mason Road site. Megacycles within the Fairview Formation are thinner (approximately 0.5 meter or less), and accompanying capping amalgamated limestone packages are thicker. Jennette (1986) and Jennette and Pryor (1993) documented four megacycles within the lower Fairview Formation. The upper Fairview Formation and the Bellevue Formation appear to represent deposition at or near fairweather wave base where signatures of both the storm-induced cycles and the larger megacycles are overprinted by nearshore reworking.

FAUNAL ANALYSIS

Investigation of the faunal assemblages in the Kope-through-Bellevue sequence reveals a complex set of factors influencing their distribution. Environmental parameters such as food availability, substrate, depth, salinity, and energy (among others) affected their arrangement on the shelf. Additionally, interspecific and intraspecific interactions were factors in faunal distribution patterns. Post-mortem processes that modified the already-existing faunal assemblages were especially important in storm-dominated systems. Many researchers have documented a relationship between the storm and shoaling cycles within the Cincinnatian and the changes in faunal assemblages (Anstey and Perry, 1972;

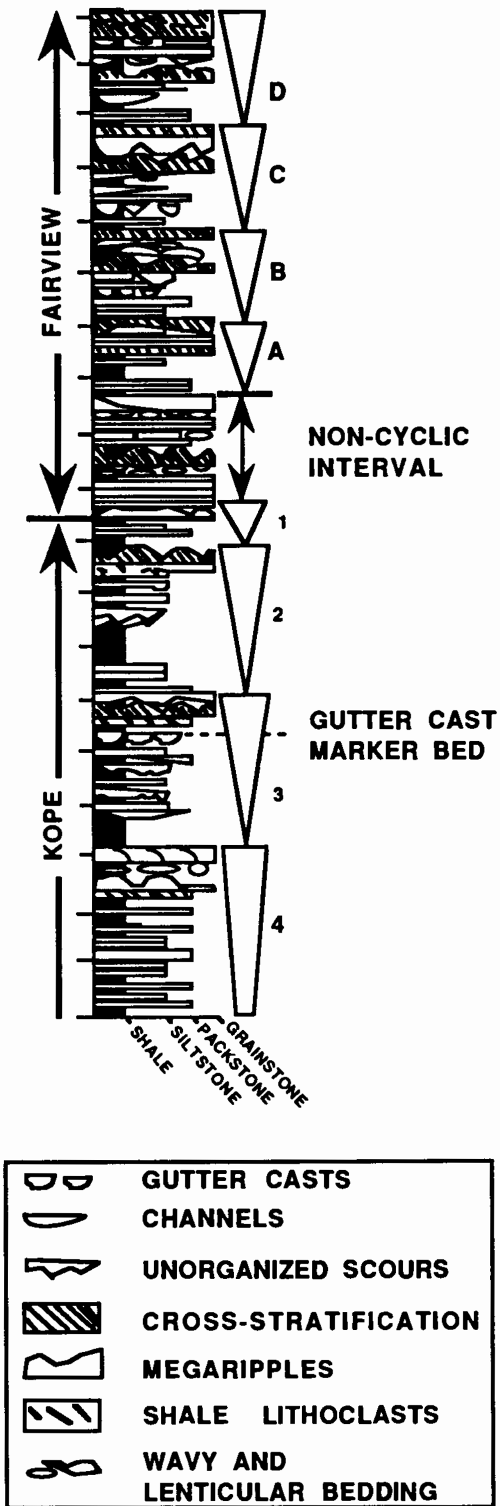


FIGURE 3-8.—Stratigraphic column showing megacycles interpreted to be shallowing sequences in the upper Kope and lower Fairview Formations (from Jennette, 1986). The scale is in meters.

Alexander, 1975; Brandt, 1980; Meyer and others, 1981, 1990; Schumacher, 1984; Jennette, 1986). Four major aspects of faunal analysis that provide insight into this relationship are abundance, diversity, paleoecology, and

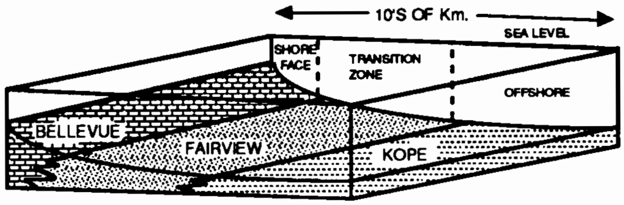


FIGURE 3-9.—Interpretation of the lateral relationship of the units in the Kope-through-Bellevue sequence (modified from Tobin, 1982).

taphonomy. Faunal-abundance data from closely spaced samples of the Kope-through-Bellevue sequence at Riedlin Road/Mason Road, in association with previously established stratigraphic control (Tobin, 1982; Jennette, 1986), paleoecology, and taphonomic indicators, were used to ascertain environmentally meaningful patterns associated with storm events and transgressive/regressive sequences (Diekmeyer, 1990). The patterns resulting from this analysis are treated in the following sections.

Cluster analysis and polar ordinations were carried out on faunal-abundance data gathered from counts of whole fossils, grid counts, and percent-rock-volume approximations (shale samples) for fragmental faunal elements in 107 samples. Percent-rock-volume approximations for fossil fragments were ascertained by weighing shale samples, washing and sieving the samples, and weighing the individual taxa (bryozoans, crinoids, and trilobites) for each size fraction. The section was sampled at approximately 0.5-meter (1.6-ft) intervals from the base to the top of the outcrop. Cluster analysis delineated seven groups of samples distinguished on the basis of faunal content. Table 3-1 describes each cluster group based upon lithologic type and characteristics, stratigraphic location, and major faunal elements. The cluster groups, hereafter just called groups, are named for their most abundant faunal elements (fig. 3-10). They are:

A. the *Onniella*-bryozoan group,
B. the *Onniella*-crinoid-trilobite group,
C. the *Rafinesquina*-bryozoan-crinoid group,
D. the *Platystrophia*-bryozoan group,
E. the *Zygospira*-bryozoan group,
F. the *Plectorthis-Rafinesquina*-crinoid group, and
G. the *Zygospira*-graptolite-trilobite group.

Although these groups are defined on fossil content, the beds within each group commonly have characteristic lithologies.

These groups were plotted onto the stratigraphic column to distinguish faunal transitions through the section (fig. 3-11). The distribution of these groups indicates a transition in faunal components from the bottom to the top of the section associated with the large-scale regression (Tobin, 1982).

FAUNAL PATTERNS ASSOCIATED WITH THE LARGE-SCALE REGRESSION

Faunal transitions from the upper Kope through the exposed Bellevue at Riedlin Road/Mason Road correspond to an increase in energy related to shallowing conditions. Successively shallowing environments were susceptible to more frequent reworking events that modified the substrate from a muddy bottom to shelly pavements. These shelly accumulations became increasingly amalgamated up section. In response, faunal assemblages range from organisms associated with relatively deep, low-energy, soft-substrate conditions to those better suited to higher energy, firmer substrate environments.

In general, smaller-valved brachiopods (*Zygospira* and *Onniella*) are replaced by larger-valved, more robust specimens (*Rafinesquina*, *Platystrophia*, *Plectorthis*, and *Hebertella*) (fig. 3-12), although *Zygospira* is an important component in discrete intervals throughout the section. The trend toward increased size and shell strength suggests increasingly energetic conditions. Increased abundance of crinoid fragments in the upper Fairview (fig. 3-13) indicates increased shelly substrate resulting from shallowing conditions. The taphonomic character of crinoid fragments ranges from well-abraded, single columnals (transported into the muddy Kope environment) through articulated stem and arm fragments (rapid burial by storm events during the time in which the upper Fairview was deposited) to abundant stem and arm fragments of varying taphonomic state (in-place winnowing and reworking during deposition of the lower Bellevue). Assemblages of crinoids indicate a relationship between environmental conditions and crinoid diversity and morphology (Meyer and others, 1990). Crinoid fragments and, more rarely, individuals are represented primarily by a low-diversity fauna, including the small, slender inadunates *Ectenocrinus* and *Cincinnaticrinus* in the Kope Formation. In the overlying Fairview, the more robust inadunate *Iocrinus* increases in abundance and is accompanied by abundant arms, stems, crowns, and individuals of the camerate *Pycnocrinus* (traditionally called *Glyptocrinus*). Stem fragments and cemented holdfasts of the large, robust inadunate *Anomalocrinus* are abundant in the Bellevue Formation (commonly associated with hardgrounds).

Morphologic variations of bryozoans also may indicate an overall shallowing trend. Assessment of general growth morphologies for each sample indicates a lack of encrusting forms in the Kope Formation, but abundance increases into the upper Fairview. Small, ramose bryozoans transcend the depth gradient, occurring in most samples. There appears to be a zone, approximately 8 meters (26 ft) thick, where massive, boxwork bryozoans occur. These colonies are mud filled, indicating burial in place, and their massive form suggests an environment turbulent enough to have maintained large numbers of filter-feeding individuals, but deep enough for them to have remained relatively undisturbed by storm events. Large, ramose bryozoans occur in the upper Kope (*Batostoma*, *Dekayia*, and *Parvohallopora* spp.), lower Fairview (*Escharopora*, *Constellaria*, *Parvohallopora* spp., *Heterotrypa*, and *Dekayia*), and upper Bellevue (*Parvohallopora ramosa*). Those in the Kope and Fairview deposits do not appear abraded and are surrounded by large amounts of mud, indicating smothering of the colonies by influxes of sediment. However, specimens from the Bellevue are abraded and lack a mud matrix, suggesting increased winnowing and possible transport.

Fragments of the trilobites *Flexicalymene* and *Isotelus* are most abundant in the Kope Formation, but have a fairly low abundance throughout the remaining section (fig. 3-14). This distribution may indicate increased disturbance frequency associated with a shallowing environment that inhibited the long-term establishment of a muddy bottom advantageous to trilobites.

Trace-fossil assemblages show a transition from a *Cruziana*-dominated ichnofacies through a mixed *Skolithos-Cruziana*-dominated ichnofacies associated with the large-

TABLE 3-1.—*Faunal groups, showing their lithologies, sedimentologic features, stratigraphic locations, and major faunal elements*

GROUP NAME	DISTINGUISHING CHARACTERISTICS	STRATIGRAPHIC LOCATION	MAJOR FAUNAL COMPONENTS
GROUP A	AMAL GS THK PL SH	KOPE CYCLE TOPS TRANSITIONAL ABOVE KOPE/FAIRVIEW	HIGH ONNIELLA HIGH BRYOZOAN INTERMEDIATE ZYGOSPIRA
GROUP B	SH SS PK WK PL BIOT	BETWEEN KOPE CYCLE TOPS	HIGH ONNIELLA INTERMEDIATE BRYOZOAN INTERMEDIATE ZYGOSPIRA INTERMEDIATE MODIOLOPSIS INTERMEDIATE TRILOBITE INTERMEDIATE CRINOID
GROUP C	PK PK/GR THN - THK UND	UPPER FAIRVIEW	HIGH BRYOZOAN HIGH RAFINESQUINA INTERMEDIATE CRINOID
GROUP D	GS PK WK AUTOCH MED - THK UND	LOWER FAIRVIEW TOPS OF FAIRVIEW CYCLES B & C TRANSITIONAL L - U FAIRVIEW UPPER BELLEVUE	HIGH BRYOZOAN INTERMEDIATE PLATYSTROPHIA INTERMEDIATE ZYGOSPIRA LOW - INTERMEDIATE RAFINESQUINA
GROUP E	GS PK SH	TRANSITIONAL KOPE/ LOWER FAIRVIEW UPPER FAIRVIEW LOWER BELLEVUE FAIRVIEW TONGUE	HIGH BRYOZOAN HIGH ZYGOSPIRA LOW - INTERMEDIATE CRINOID
GROUP F	GS PK SH THN - THK	LOWERMOST UPPER FAIRVIEW	HIGH PLECTORTHIS INTERMEDIATE - HIGH CRINOID INTERMEDIATE RAFINESQUINA
GROUP G	AUTOCH PK/WK SH SS	MIAMITOWN SHALE BETWEEN KOPE CYCLE TOPS	HIGH ZYGOSPIRA HIGH TRILOBITE HIGH GRAPTOLITE

KEY:
AMAL- AMALGAMATED BEDS
GS-GRAINSTONE
PK-PACKSTONE
WK-WACKESTONE
SH-SHALE
SS-SILSTONE
UND-UNDULATING BEDS
PL-PLANAR BEDS
THN -THIN BEDS
MED-MEDIUM BEDS
THK-THICK BEDS
BIOT-BIOTURBATION
AUTOCH-AUTOCHTHONOUS FOSSIL ACCUMULATIONS
BRACHIPOD PAVEMENTS
FINING UPWARD SEQUENCE
COARSENING UPWARD SEQUENCE
SHALE RIP-UP CLASTS
BRACHIOPODS
BRYOZOANS

scale regression (Tobin, 1982). Abundant *Diplocraterion*, representative of the *Skolithos* facies, are present in the upper Kope Formation. Three separate ichnospecies occur in a calcareous siltstone near the top of the formation (Meyer and others, 1981). This bed is laterally traceable across the outcrop. Present-day organisms living in U-shaped burrows commonly occur in relatively shallow, well-oxygenated and well-lighted environments. Fürsich (1974, 1975) attributed *Diplocraterion* to a high-energy intertidal or very shallow subtidal environment. The abundance of *Diplocraterion* in an environment interpreted to have been at or below storm wave base requires further study.

FAUNAL PATTERNS WITHIN THE KOPE FORMATION

Megacycles in the Kope and lower Fairview distinguished by Tobin (1982), Jennette (1986), and Jennette and Pryor (1993) are represented by a repetitive succession of certain faunal groups. The *Onniella*-bryozoan group (A) is restricted to the Kope megacycle tops and lowermost Fairview. The *Onniella*-crinoid-trilobite group (B) is associated with the multiple-event packstones and wackestones between the Kope megacycle tops. The *Zygospira*-graptolite-trilobite group (G) occurs in the thin packstones/wackestones and shales between Kope megacycle tops (high trilobite abun-

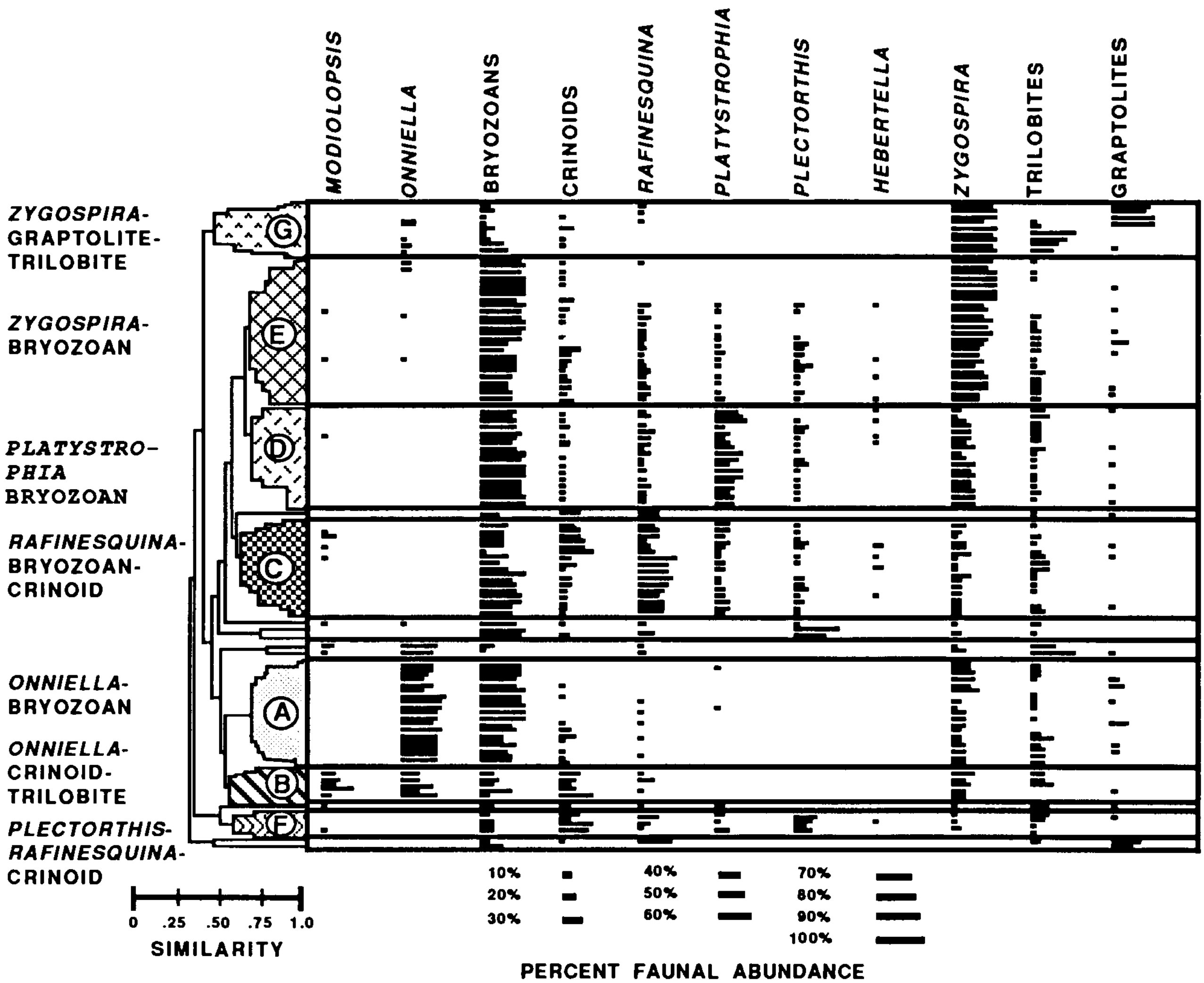


FIGURE 3-10.—The seven faunal groups showing the relative abundances of major faunal elements within each group. Percent abundances are indicated by the lengths of the bars for the faunal elements. The bar graph on the left shows the level of similarity among samples within each group and between groups. Similarity ranges from perfect correspondence, with a value of 1.0, to completely dissimilar, with a value of 0. Samples not falling within any group also are indicated.

dance) and in the Miamitown Shale (high graptolite abundance). Polar ordination reveals a nearly linear distribution of groups A, B, and G along a gradient associated with *Zygospira* and *Onniella* relative abundances. The lowest relative abundance of *Onniella* and highest relative abundance of *Zygospira* are in the packstones, wackestones, and shales of group G. These strata represent smothering of distal communities by shale and silt during waning storm conditions or transport of bioclastic material into deeper muds by storm surge. As depth became increasingly shallow, reworking of carbonate materials produced the amalgamated packstones and wackestones of group B that contain an intermediate abundance of *Onniella*. The amalgamated grainstones (group A) contain the highest abundance of *Onniella* and represent the shallowest conditions in the Kope Formation. However, analysis of within-bed distribution of *Onniella* and *Zygospira* reveals increasing *Zygospira* from bed bottom to bed top. Morphologic assessment of these two brachiopods suggests that *Onniella*'s flat, more delicate valves were more suited to a muddier substrate where they could "float" at the sediment-water interface. The common disarticulation and the abraded appearance of the valves may indicate that they were winnowed from the muds and reworked into the amalgamated beds by storm events. In contrast, the stronger articulation and greater density of the shells of *Zygospira* would have allowed animals of that genus to live on substrates associated with increased energy. Shells of *Zygospira* commonly are attached to bioclasts, including other *Zygospira* shells and crinoid stems (Meyer and others, 1981), suggesting that the animals had the ability to live in association with the shelly accumulations characteristic of shallowing conditions.

FAUNAL PATTERNS WITHIN THE FAIRVIEW FORMATION

Tobin (1982) interpreted the Fairview Formation to be the result of an environment intermediate between the deeper water Kope Formation and the shallower

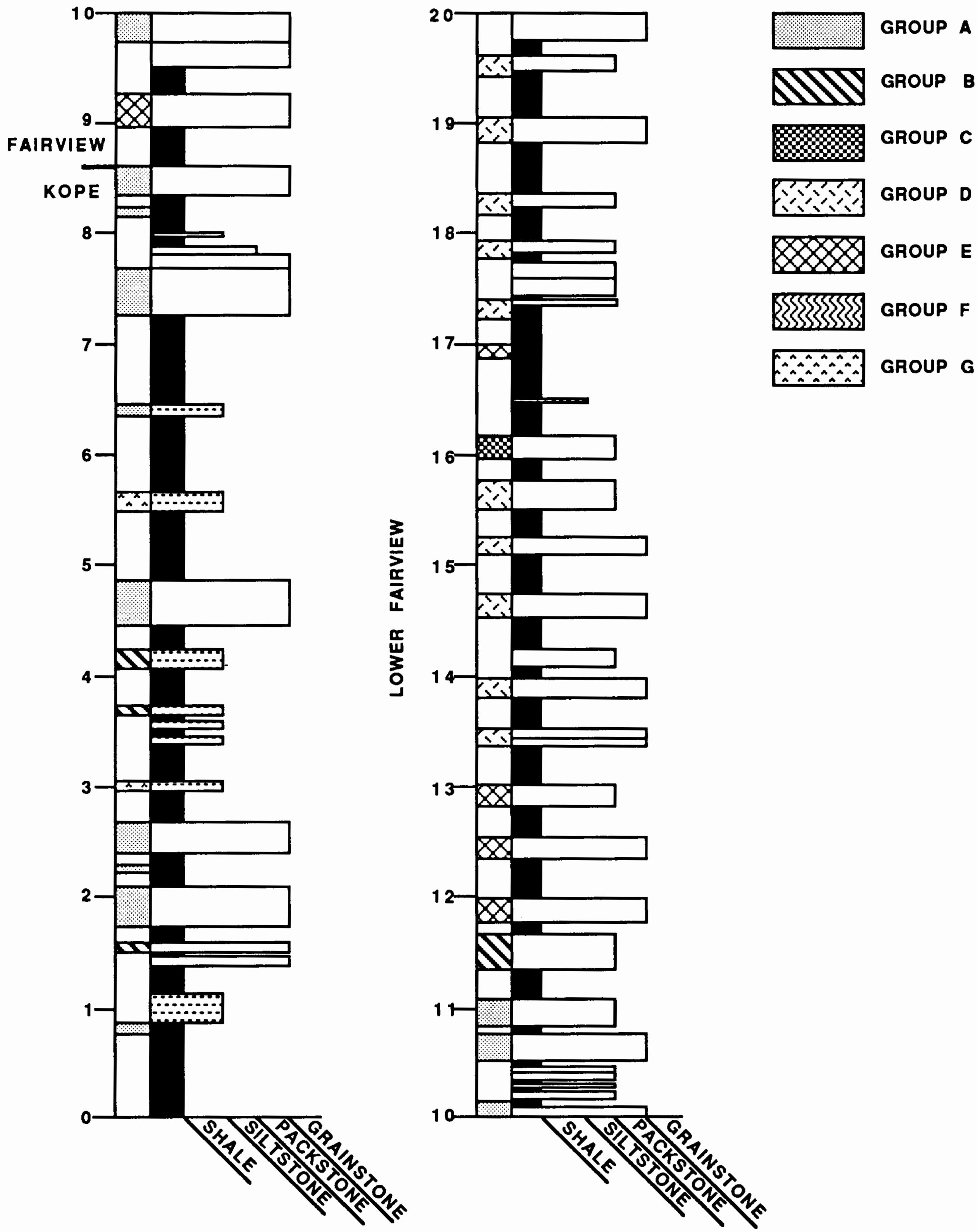
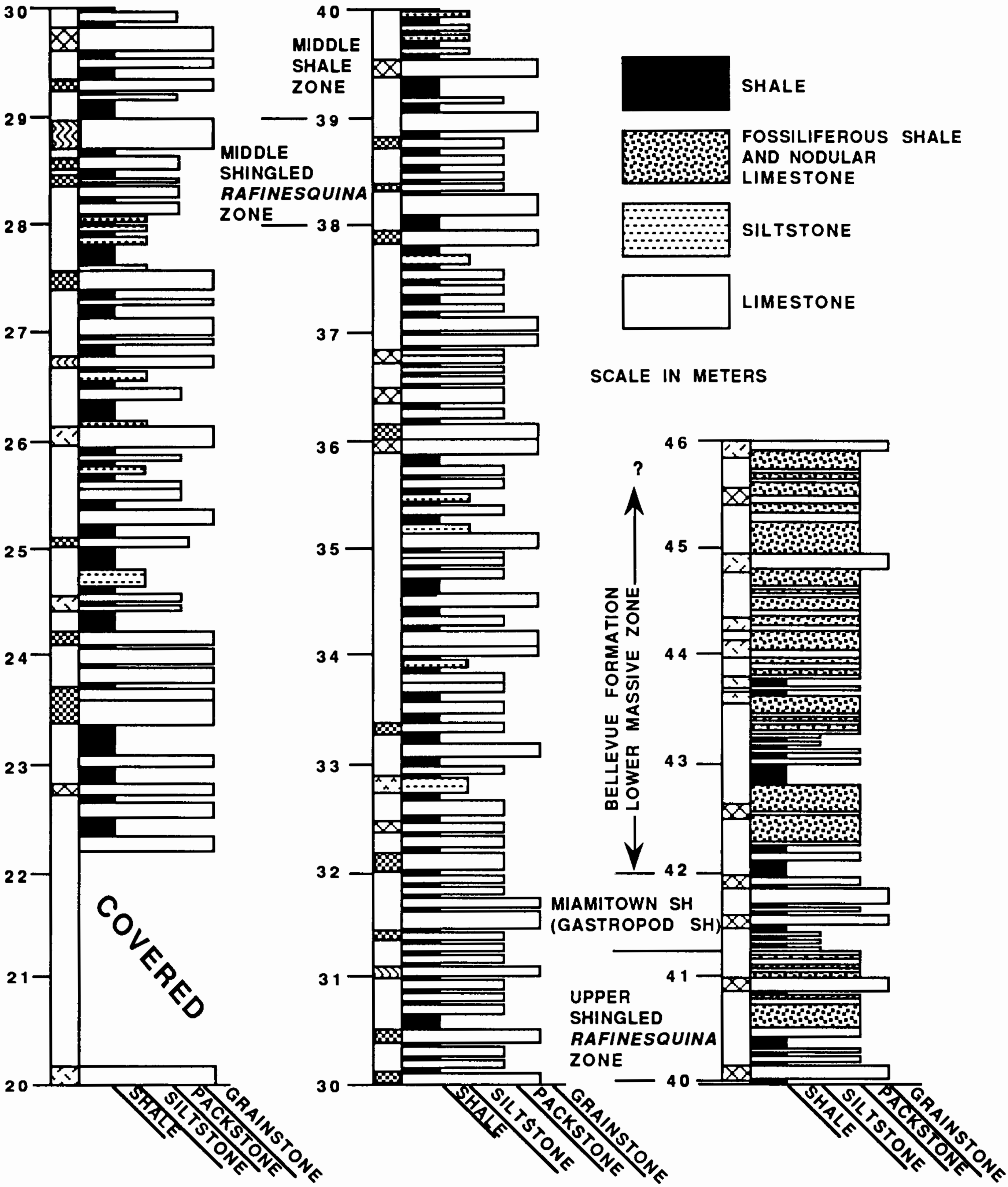


FIGURE 3-11.—Stratigraphic column of the Riedlin Road/Mason Road site; lithologies are noted by patterns and widths of those in figure 3-10.



beds. Patterned blocks on the left of the column indicate the location of each sample and its faunal group. These patterns correspond to

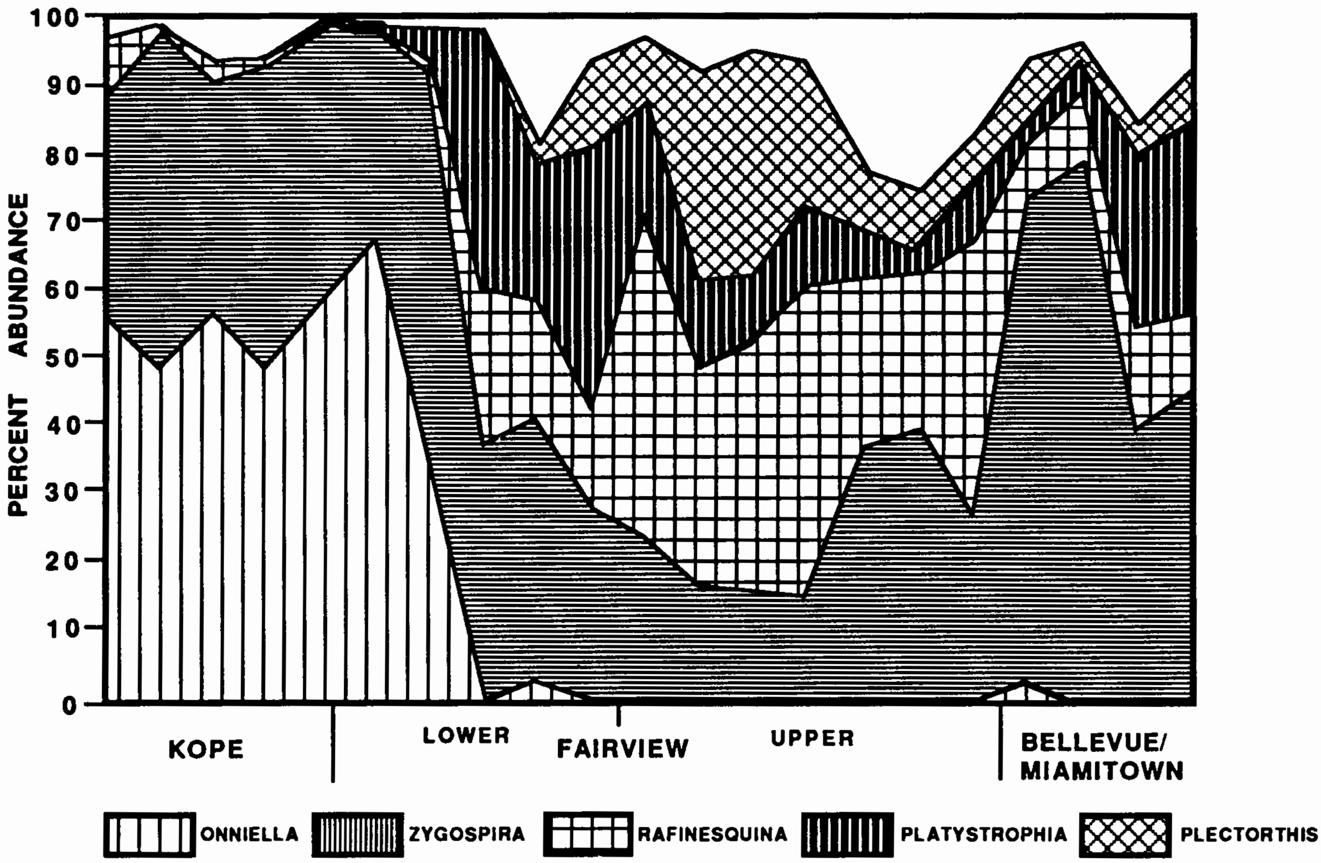


FIGURE 3-12.—Distribution of five major brachiopod genera from the base (left) to the top (right) of the section, based on a five-point moving average of percent relative abundance.

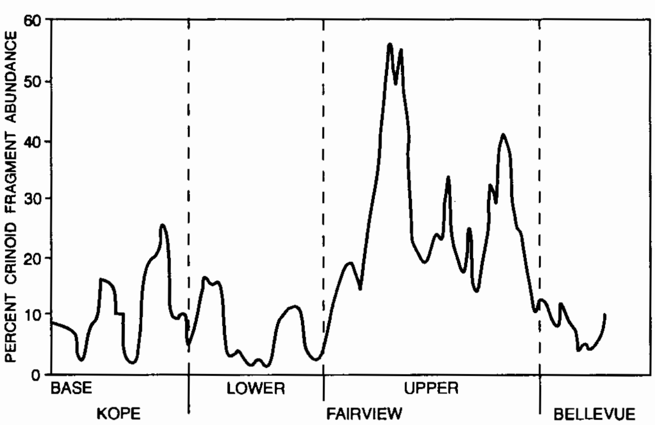


FIGURE 3-13.—Percent relative abundance of crinoid fragments from the base (left) to the top (right) of the section.

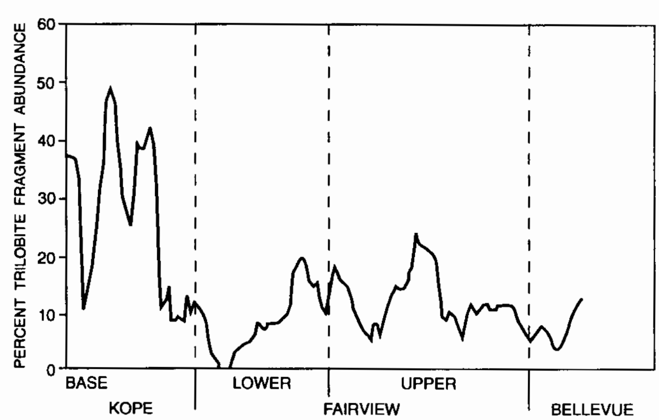


FIGURE 3-14.—Percent relative abundance of trilobite fragments from the base (left) to the top (right) of the section.

water Bellevue Formation. On the basis of multivariate analyses of faunal-abundance data, several faunal patterns emerge (fig. 3-11). The *Zygospira*-bryozoan group (E) appears to be transitional between the Kope and lower Fairview and is intercalated with the upper Kope groups. The *Platystrophia*-bryozoan group (D) dominates the lower Fairview, stratigraphically replacing group E. The upper Fairview is characterized by alternating limestone beds containing groups C, D, E, and F, representing dominance by *Rafinesquina*, *Platystrophia*, *Zygospira*, and *Plectorthis*, respectively. *Zygospira*-dominated group E becomes increasingly common approaching the Bellevue contact and may be related to the lower tongue of the Miamitown Shale facies. Throughout the Fairview, the trend appears to be one of frequent disruption of community structure by events that concentrated and enhanced relative abundances of distinct faunal components. Following the final event represented in each amalgamated bed, there developed a new community that may or may not have contained the same dominant faunal elements as in the previous bed. As a result of the amalgamating nature of storm events, fine-scale faunal patterns (megacycles) are difficult to distinguish within the

Fairview Formation. However, a general pattern of increased size and robustness of brachiopod valves through the Fairview is evident and corresponds to decreased thicknesses of intervening shales associated with thinner, more abundant limestone beds.

FAUNAL PATTERNS OF THE BELLEVUE/ MIAMITOWN INTERVAL

The Bellevue interval represents the shallowest environment of the Kope-through-Bellevue large-scale regression of Tobin (1982). Researchers have interpreted the Miamitown Shale to be the result of one of the following: (1) a deepening event within the shallow Bellevue environment, (2) an increased clastic supply to the shelf, (3) variation in water chemistry, or (4) deposition in a lagoon (see Tobin, 1982, for summary). Continuing research points to the intimate relationship between the Miamitown and Bellevue facies based upon their interfingering relationship on a regional scale (see Dattilo, paper 7 in this volume). The overlap of faunal elements within these facies at the Riedlin Road/ Mason Road site lends credence to this interpretation (fig. 3-11). The "Middle Shale Zone," "upper shingled *Rafinesquina* Zone," and the Miamitown Shale ("Gastropod Shale") intervals are characterized by the *Zygospira*-bryozoan group (E). Further, *Cyclonema* exhibits increased abundance in this interval, as do *Ambonychia* and *Caritodens*. Samples from the upper Miamitown facies fall into the *Zygospira*-graptolite-trilobite group (G). Samples in group G with high abundances of graptolites are found in this Miamitown interval, whereas samples with high abundances of trilobites are found in the Kope shales (fig. 3-10). The "Lower Massive Zone" of the Bellevue Formation contains a relatively high abundance of the large brachiopods *Platystrophia*, *Plectorthis*, *Hebertella*, and, less commonly, *Zygospira* and *Rafinesquina*, indicating shallowing conditions. Because of their large size and robustness, they were better suited for withstanding the higher energy associated with an environment at or near fair-weather wave base. Bryozoans are more abundant than in underlying beds and are represented by large and small ramose morphotypes and abundant encrusting and foliaceous types. Size sorting is common in the upper Bellevue; large brachiopod valves dominate the bottoms of beds, and *Zygospira* is abundant on the bed tops. Fossil fragments give additional evidence for shallowing conditions. Crinoid columnals in the lower Bellevue are associated with abundant arm plates, indicating possible winnowing but very little, if any, transport (Meyer and Meyer, 1986). The winnowing model for the Bellevue is substantiated by increased sorting of skeletal fragments, variable states of abrasion, and small average size of bioclasts.

Analyses of faunal-abundance data, taphonomy, and paleoecology, in association with increased understanding of facies relationships within storm-dominated systems, allow the reconstruction of an integrated depositional model. Figure 3-15 shows the distribution of faunal groups along the Cincinnatian ramp for the Kope, Fairview, and Bellevue/ Miamitown intervals at the Riedlin Road/Mason Road site. Gathering and analyzing faunal, stratigraphic, and lithologic data on a regional scale (Holland, 1990, 1993) provides a model for large-scale depositional patterns within Upper Ordovician strata. In addition, future research using faunal data from closely spaced lateral and vertical samples collected from Cincinnati and adjacent areas will provide the basis for interpreting the emerging, smaller scale patterns and for "fine tuning" regional models.

ADDITIONAL LOCALITIES

For more information on localities, see Appendix A at the end of this volume.

"Lexington Limestone"
Sugar Creek (KY-GA-0001), contact with Kope

Point Pleasant
Bear Creek (OH-CT-0010) - 69 ft (21 meters); contact with overlying Kope
Boat Run (OH-CT-0011) - 52 ft (15.8 meters); contact with overlying Kope
Bradford (KY-BK-0001) - 63 ft (19.2 meters); base of Kope estimated by Weiss and others (1965) to be 15 ft (4.6 meters) higher than exposed section
Chilo (OH-CT-0012) - 11 ft (3.4 meters)
Foster (KY-BK-0003) - 60 ft (18.3 meters)
Kope Hollow (OH-BR-0003) - 32 ft (9.8 meters)
North Point Pleasant (OH-CT-0016) - 53 ft (16.2 meters)
Slickaway Run (OH-CT-0017) - 4 ft (1.2 meters)
Twelvemile Creek (OH-CT-0018) - 6.5 ft (2.0 meters), upper contact

Kope Formation
Arnold Creek (IN-O-0002)
Aurora (IN-D-0001)
Backbone Creek (OH-CT-0006) - 30 meters (98.4 ft)
Bald Knob (OH-HA-0013) - 7.6 meters (24.9 ft)
Batavia #1 (OH-CT-0001) - 16 meters (52.5 ft) of upper Kope
Bear Creek (OH-CT-0010) - 70 ft (21.3 meters); contact with underlying Point Pleasant
Bellevue Hill (OH-HA-0003) - 37 ft (11.3 meters)
Boat Run (OH-CT-0011) - 72 ft (21.9 meters); contact with underlying Point Pleasant
Briarly Creek (OH-HA-0014) - 19 ft (5.79 meters)
Camp Claybanks (OH-HA-0015) - 12 ft (3.7 meters)
Chilo (OH-CT-0012) - 30 ft (9.1 meters)
Congress Run (OH-HA-0016)
Covington (KY-KE-0004) - 30.5 meters (100.1 ft)
Crosby Road (OH-HA-0017) - 32 ft (9.7 meters)
Eightmile Creek (OH-HA-0034)
Fort Thomas (KY-CP-0001) - 59 meters (193.6 ft)
Foster (KY-BK-0003) - 10 ft (3.05 meters) + another 50 ft (15.2 meters) poorly exposed above that
Galbraith Road (OH-HA-0032) - 2 ft (0.6 meter) to base of Fairview
Galbraith Road, cliff section (OH-HA-0033) - 34 ft (10.4 meters)
Georgetown (OH-BR-0006 - 8.9 meters (29.2 ft)
Grand Avenue (OH-HA-0006) - 94 ft (28.7 meters) from quarry floor to Maysville
Happy Hollow (OH-CT-0013)
I-275/Turkeyfoot Road (KY-KE-0005) - 12.5 meters (41.0 ft)
Indian Creek (OH-CT-0014)
Jackson Hill Park (OH-HA-0018) - 6.1 meters (20 ft)
Johns Hill (KY-CP-0005) - 8.7 meters (28.5 ft)
Kope Hollow (OH-BR-0003) - 151 ft (46.0 meters); one of three co-equal type sections of Kope
Maysville (KY-MS-0004) - one of three co-equal type

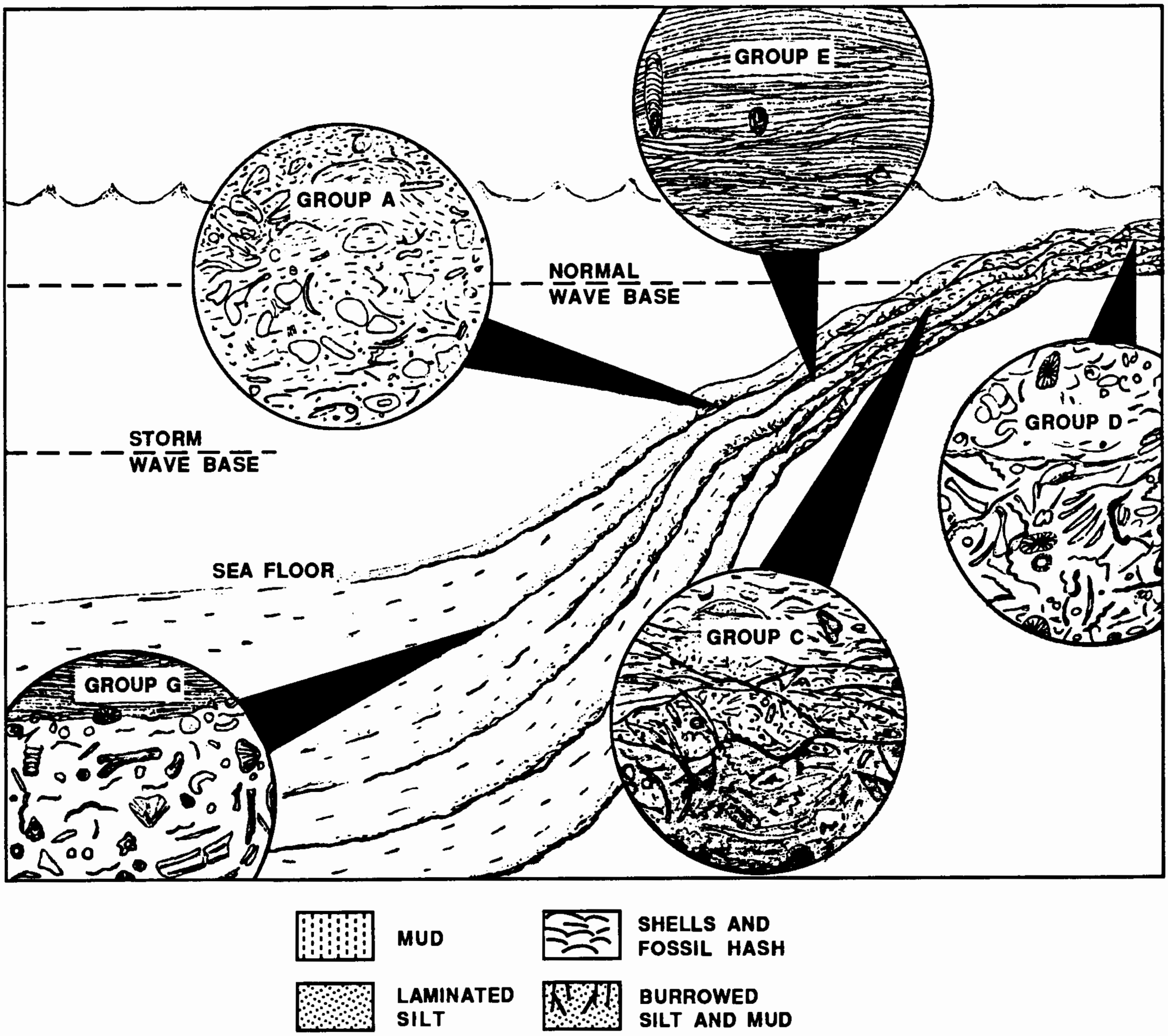


FIGURE 3-15.—Reconstructed distribution of five of the faunal groups along the Cincinnatian ramp, showing the characteristic lithologies and fauna (based on Brett and others, 1986).

sections of Kope
Miami Station (OH-HA-0019) - 53 ft (16.2 meters)
Miamitown/Hamilton-Cleves exit (OH-HA-0009) - 19.9 meters (65.2 ft)
Millvale (OH-HA-0035) - 106 ft (32.3 meters) in middle and upper parts
Montana Avenue (OH-HA-0038) - 15.6 meters (51.2 ft)
Muddy Creek (OH-HA-0020) - 106 ft (32.3 meters)
Newport-Grand Avenue (KY-CP-0004) - 26 meters (85.3 ft)
Newport Shopping Center (KY-CP-0002) - 164 ft (50.0 meters); upper contact
Ninemile Creek (OH-CT-0015) - about 177 ft (54 meters), upper contact
North Point Pleasant (OH-CT-0016) - 65 ft (19.8 meters)
Orphanage Road (KY-KE-0003) - 30 meters (98.4 ft)
Pabco/Timberview Apartments (OH-HA-0037) - 29.4 meters (96.5 ft), upper contact
Rabbit Hash (KY-BE-0002)
Rapid Run (OH-HA-0036) - 202 ft (61.57 meters), upper contact
Red Oak Creek (OH-BR-0004) - one of three co-equal type sections of Kope
Rising Sun (IN-O-0001) - 52 ft (15.8 meters), upper contact
Riverside (OH-HA-0021) - 81 ft (24.7 meters), both contacts
Sekitan Road (OH-HA-0022) - 62 ft (18.9 meters)
Slickaway Run (OH-CT-0017) - 171 ft (52.1 meters)
Southgate (KY-CP-0003) - 23.2 meters (76.1 ft)
Sugar Creek (KY-GA-0001), contact with “Lexington”
Tanners Creek (IN-D-0003) - 22 ft (6.7 meters), up-

per contact
Twelvemile Creek (OH-CT-0018) - 108.5 ft (33.07 meters), lower contact
West Fork (OH-HA-0024) - 110 ft (33.5 meters)
West Harrison (IN-D-0004)
White Swan Run (OH-BR-0010) - 161 ft (49.1 meters), to base of Maysvillian
Wiley Branch (IN-SW-0001)

Grand Avenue Member of Kope Formation
Bald Knob (OH-HA-0013)
Grand Avenue (OH-HA-0006) - type section
Miami Station (OH-HA-0019) - 11 ft (3.4 meters)
Miamitown/Hamilton-Cleves exit (OH-HA-0009)
Muddy Creek (OH-HA-0020) - 12 ft (3.7 meters)
Riverside (OH-HA-0021) - 11 ft (3.4 meters), both contacts
Sekitan Road (OH-HA-0022)
West Fork (OH-HA-0024)

Wesselman Tongue of Kope Formation
Briarly Creek (OH-HA-0014) - 5 ft (1.52 meters)
Congress Run (OH-HA-0016)
Miami Station (OH-HA-0019) - 27 ft (8.2 meters)
Miamitown/Hamilton-Cleves exit (OH-HA-0009)
Muddy Creek (OH-HA-0020) - 4 ft (1.2 meters)
Riedlin Road/Mason Road (KY-KE-0001) - 8.5 meters (27.9 ft), upper contact
Sekitan Road (OH-HA-0022) - 14 ft (4.3 meters)
Wesselman (OH-HA-0011) - bounded above and below by Fairview; type section
West Fork (OH-HA-0024) - 11 ft (3.4 meters)

Fairview Formation
Aiken School (OH-HA-0012) - 26 ft (7.9 meters)
Aurora (IN-D-0001)
Backbone Creek (OH-CT-0006) - 30 meters (98.4 ft)
Bald Knob (OH-HA-0013) - 9.7 meters (31.8 ft)
Batavia #2 (OH-CT-0002) - 12.1 meters (39.7 ft)
Bellevue Hill (OH-HA-0003) - 108 ft (32.9 meters)
Briarly Creek (OH-HA-0014)
Brookville Dam spillway (IN-FR-0002) - in highwall
Camp Claybanks (OH-HA-0015) - 84 ft (25.6 meters)
Congress Run (OH-HA-0016)
Covington (KY-KE-0004) - 3 meters (9.8 ft)
Crosby Road (OH-HA-0017) - 63 ft (19.2 meters)
East Fork Reservoir spillway/Wm. A. Harsha Lake (OH-CT-0007)
Eightmile Creek (OH-HA-0034)
Emming Street (OH-HA-0002)
Fairview Park (OH-HA-0001) - original type section of Fairview Formation
Fort Thomas (KY-CP-0001)
Galbraith Road, cliff section (OH-HA-0033) - 73 ft (22.3 meters)
Georgetown (OH-BR-0006) - 9.2 meters (30.2 ft)
Happy Hollow (OH-CT-0013)
I-275/Turkeyfoot Road (KY-KE-0005) - 0.7 meter (2.3 ft)
Jackson Hill Park (OH-HA-0018) - 33.2 meters (109 ft)
Johns Hill (KY-CP-0005) - 8.0 meters (26.2 ft)
Miami Station (OH-HA-0019) - 29 ft (8.8 meters)
Miamitown/Hamilton-Cleves exit (OH-HA-0009) - 0.2 meter (0.7 ft)
Montana Avenue (OH-HA-0038) - 0.3 meter (1.0 ft)
Muddy Creek (OH-HA-0020) - 67 ft (20.4 meters)
Newport-Grand Avenue (KY-CP-0004) - 2.9 meters (9.5 ft)
Pabco/Timberview Apartments (OH-HA-0037) - 0.5 meter (1.6 ft), lower contact
Riedlin Road/Mason Road (KY-KE-0001) - 32.6 meters (107 ft), both contacts
Riverside (OH-HA-0021) - 39 ft (11.9 meters), lower contact
Sekitan Road (OH-HA-0022) - 26 ft (7.9 meters)
Sheits Road (OH-HA-0023) - 38 ft (11.6 meters), upper contact
Southgate (KY-CP-0003) - 0.5 meter (1.6 ft)
Stonelick Creek (OH-CT-0004) - Fairview-Bellevue contact at Belfast-Owensville Road bridge over Stonelick Creek, about 1.2 miles (2 km) southeast of Ohio Rte. 131 at 39°09'40"N, 84°07'35"W
Tanners Creek (IN-D-0003) - 41 ft (12.5 meters), lower contact
Wesselman (OH-HA-0011) - above and below rock of the Wesselman Tongue of Kope Formation
West Fork (OH-HA-0024) - 43 ft (13.11 meters)

North Bend Tongue of Fairview Formation
Briarly Creek (OH-HA-0014) - 11 ft (3.35 meters)
Congress Run (OH-HA-0016)
Galbraith Road, cliff section (OH-HA-0033) - 18 ft (5.5 meters)
Miami Station (OH-HA-0019) - 8 ft (2.4 meters)
Miamitown/Hamilton-Cleves exit (OH-HA-0009)
Muddy Creek (OH-HA-0020) - 20 ft (6.1 meters)
North Bend (OH-HA-0010) - type section
Sekitan Road (OH-HA-0022) - 10 ft (3.0 meters)
West Fork (OH-HA-0024) - 19 ft (5.8 meters)

Mt. Hope Member of Fairview Formation
Maysville (KY-MS-0004) - 40.8 meters (133.9 ft)

Fairmount Member of Fairview Formation
Maysville (KY-MS-0004) - 21.6 meters (70.9 ft)

Miamitown Shale
Aiken School (OH-HA-0012) - 5 ft (1.5 meters)
Bald Knob (OH-HA-0013)
Batavia #2 (OH-CT-0002) - 0.9-1.2 meters (3.0-3.9 ft)
Bellevue Hill (OH-HA-0003) - 5 ft (1.5 meters)
Briarly Creek (OH-HA-0014)
Brookville Dam spillway (IN-FR-0002)
Camp Claybanks (OH-HA-0015) - 8 ft (2.4 meters)
Congress Run (OH-HA-0016)
Crosby Road (OH-HA-0017) - 21 ft (6.4 meters)
Emming Street (OH-HA-0002)
Fairview Park (OH-HA-0001)
Galbraith Road, cliff section (OH-HA-0033) - 7 ft (2.1 meters)
Jackson Hill Park (OH-HA-0018) - 1.2 meters (4.0 ft)
Miami Station (OH-HA-0019)
Miamitown West (OH-HA-0008) - 5.2 meters (17.0 ft)
Muddy Creek (OH-HA-0020) - 5 ft (1.5 meters)
Rice and Gage Streets (OH-HA-0004)
Riedlin Road/Mason Road (KY-KE-0001) - 1.0 meter (3.3 ft), both contacts
Sekitan Road (OH-HA-0022)
Sheits Road (OH-HA-0023) - 14 ft (4.3 meters), both contacts

West Fork (OH-HA-0024)
Wynbrook Apartments (OH-HA-0025)

Bellevue Limestone Member of Grant Lake Formation

Aiken School (OH-HA-0012) - 23 ft (7.0 meters)
Aurora (IN-D-0001)
Backbone Creek (OH-CT-0006) - 8 meters (26.2 ft)
Batavia #2 (OH-CT-0002) - 7.9 meters (25.9 ft)
Bellevue Hill (OH-HA-0003) - 22 ft (6.7 meters)
Brookville Dam spillway (IN-FR-0002)
Camp Claybanks (OH-HA-0015) - 3 ft (0.9 meter)
Emming Street (OH-HA-0002)
Fairview Park (OH-HA-0001)
Galbraith Road, cliff section (OH-HA-0033) - 20 ft (6.1 meters)
Georgetown (OH-BR-0006) - 14.8 meters (48.6 ft)
Jackson Hill Park (OH-HA-0018) - 6.71 meters (22 ft)
Madison South road cut (IN-JE-0003) - 0.25 meter (0.8 ft)
Maysville (KY-MS-0004) - 22.6 meters (74.1 ft)
Miamitown West (OH-HA-0008) - 2.1 meters (7 ft)
Muddy Creek (OH-HA-0020) - 29 ft (8.8 meters)
Rice and Gage Streets (OH-HA-0004)
Riedlin Road/Mason Road (KY-KE-0001) - 4.5 meters (14.7 ft), lower contact
Sheits Road (OH-HA-0023) - 42 ft (12.8 meters)
Stonelick Creek (OH-CT-0004) - Fairview-Bellevue contact at Belfast-Owensville Road bridge over Stonelick Creek, about 1.2 miles (2 km) southeast of Ohio 131 at 39°09'40"N, 84°07'35"W
Wynbrook Apartments (OH-HA-0025)

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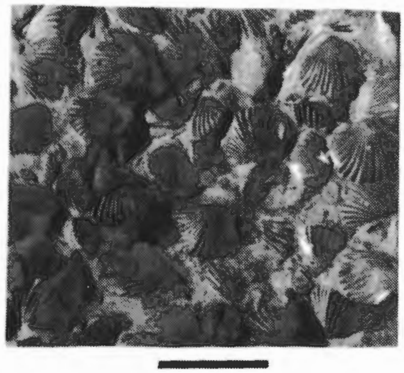
Address of author: Sharon C. St. Louis Diekmeyer, Department of Geology, University of Cincinnati, Cincinnati, OH 45221-0013.

FIGURE 3-16.—Cincinnatian brachiopods, crinoids, trilobites, and bryozoans. Scales bars = 1 cm; UCGM = University of Cincinnati Geology Museum; UCGM PT = University of Cincinnati Paleontology Teaching Collection.

1 *Zygospira cincinnatiensis* Meek, 1873, UCGM 7351.
2 *Onniella meeki* (S. A. Miller, 1875), University of Cincinnati Teaching Collection.
3 *Ectenocrinus* sp.
4 *Isotelus maximus* Locke, 1838, UCGM PT 220; note hypostome (circled).
5 *Flexicalymene meeki* (Foerste, 1910), UCGM 40681; note disarticulation in the specimen on the right.
6 *Batostoma jamesi* (Nicholson, 1874), UCGM.
7 *Homotrypa wortheni* (James, 1882), UCGM P527.



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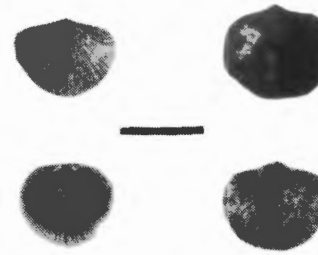

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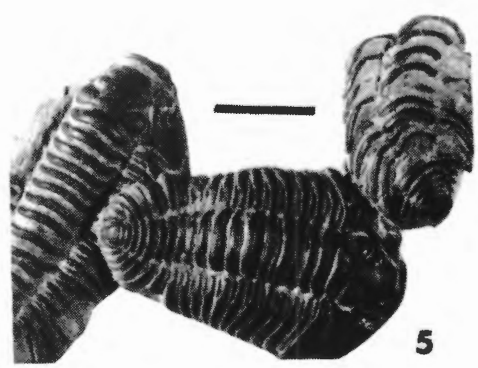

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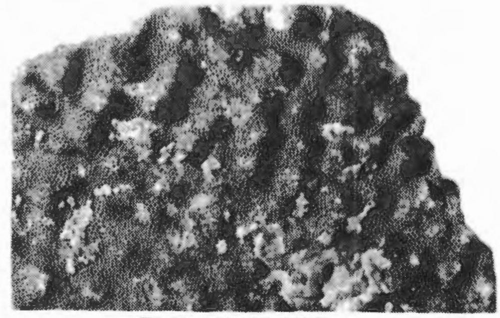

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FIGURE 3-17.—Cincinnatian brachiopods, crinoids, and bryozoans. Scales bars = 1 cm; UCGM = University of Cincinnati Geology Museum; UCGM PT = University of Cincinnati Paleontology Teaching Collection.

1a, b *Platystrophia laticosta* (Meek, 1873), brachial and pedicle valve, respectively.
2 *Plectorthis fissicosta* (Hall, 1847), University of Cincinnati Teaching Collection.
3a *Strophomena planoconvexa* (Hall, 1847), brachial valve, exterior, UCGM 8-260.
3b *Strophomena planumbona* (Hall, 1847), pedicle valve, interior; note prominent muscle scars, University of Cincinnati Teaching Collection.
4 *Iocrinus subcrassus* (Meek & Worthen, 1865), part of stem.
5 *Pycnocrinus dyeri* (Meek, 1872), calyx, UCGM 17596.
6 *Dekayia aspera* Milne-Edwards & Haime, 1851, UCGM 20398.
7 *Escharopora falciformis* (Nicholson, 1875), UCGM.
8 *Constellaria florida* Ulrich, 1882.
9 *Heterotrypa frondosa* (d'Orbigny, 1850), UCGM 20390.

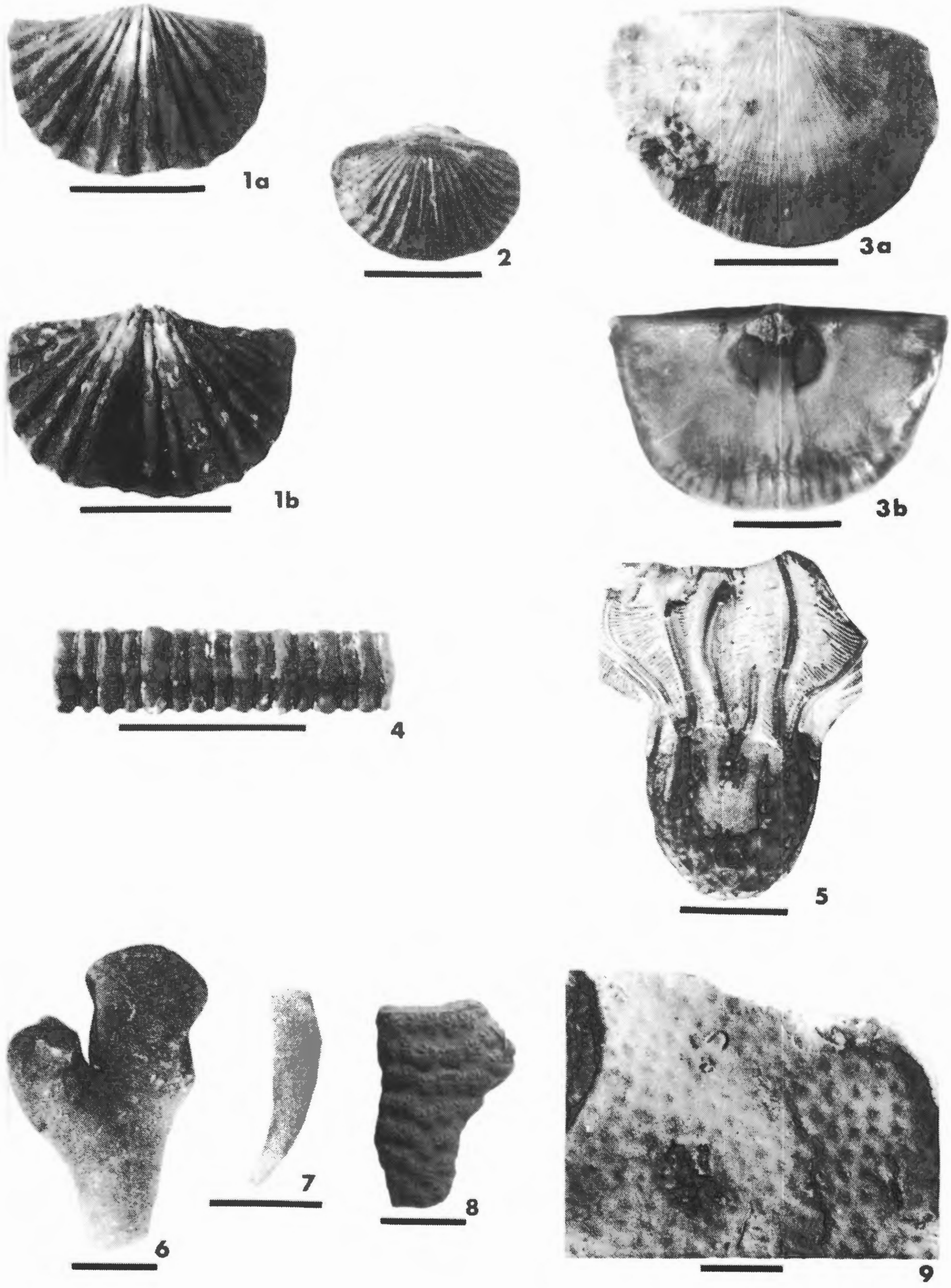
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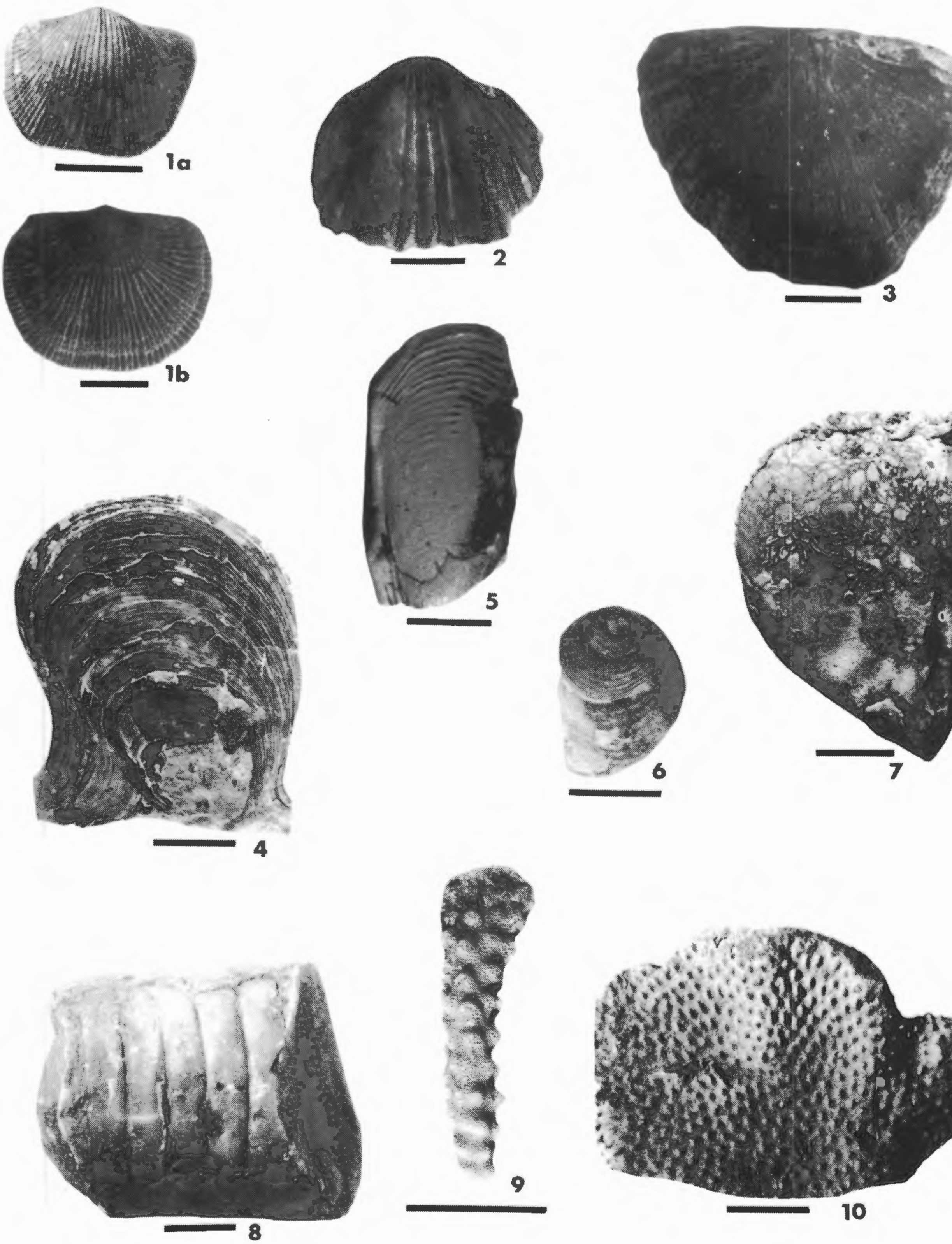
FIGURE 3-18.—Cincinnatian brachiopods, mollusks, and bryozoans. Scales bars = 1 cm; UCGM = University of Cincinnati Geology Museum; UCGM PT = University of Cincinnati Paleontology Teaching Collection.

1a, b *Hebertella occidentalis* Hall, 1847, brachial and pedicle valve, respectively, University of Cincinnati Teaching Collection.
2 *Platystrophia ponderosa* Foerste, 1909, pedicle valve, University of Cincinnati Teaching Collection.
3 *Rafinesquina alternata* (Emmons, 1842), pedicle valve, UCGM P238.
4 *Caritodens demissa* (Conrad, 1842), UCGM.
5 Modiolopsid pelecypod, internal mold.
6 *Cyclonema inflatum* Ulrich, 1897.
7 *Ambonychia* sp., internal mold; note cyclostome bryozoans on surface of mold, University of Cincinnati Teaching Collection.
8 ?*Orthonybyoceras* sp., internal mold with encrusting bryozoans.
9 *Parvohallopora ramosa* (d'Orbigny, 1850).
10 *Monticulipora molesta* Nicholson, 1881, UCGM 20356.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4. UPPER KOPE (MCMICKEN) COLLECTING ON THE MIAMITOWN/HAMILTON-CLEVES EXIT RAMP (UPPER ORDOVICIAN, SOUTHWESTERNMOST OHIO)

by
Roger J. Cuffey

SIGNIFICANCE

This locality (OH-HA-0009) provides excellent access to a prolific bryozoan fauna of late Edenian age. This fauna has been thoroughly studied by Anstey and Perry (1972) and thus serves as a comparative standard for that phylum and age within the type-Cincinnatian region.

LOCATION

The strata yielding this bryozoan fauna are exposed in the road cut along the south side (away from the main highway) of the exit ramp in the southwestern quadrant of the interchange between I-74 (here also I-275) and Ohio Route 128 (Hamilton-Cleves Road), 0.8 mile (1.3 km) south-southwest of the crossroads in the center of Miamitown, Hamilton County, Ohio (fig. 4-1). This exit ramp takes the eastbound traffic off the interstate. The shoulders of both the ramp itself and the crossroad at the bottom of the ramp are wide enough to provide parking out of the way of any exiting traffic. Permission to examine the cut should be obtained from the Ohio Department of Transportation. The ramp lies in the center SE¼SE¼ sec. 1, T. 1 N., R. 1 E., on the Addyston, Ohio–Kentucky, 7.5-minute quadrangle, at 39°12'21"N latitude, 84°42'39"W longitude (4341928 m N, 697649 m E, UTM zone 16).

The heavy traffic on both lanes of the interstate above effectively separates this exit ramp from the road cuts along the north side of the interstate. Those cuts include the type section of the Miamitown Shale (Ford, 1967), discussed fully by Dattilo (paper 7 in this volume; OH-HA-0008).

STRATIGRAPHY AND PALEONTOLOGY

The road cut (fig. 4-2) exposes about 20 meters (60 ft) of gray shale with minor, interbedded, thin, bioclastic to barren limestones, characteristic of the upper part of the Kope Formation, equivalent to the McMicken of the traditional type-Cincinnatian units (Anstey and Perry, 1972, p. 35, 77; they used the term Eden Shale). Most abundant and most conspicuous of the numerous fossils weathering out on the outcrop surface are branching bryozoan fragments, mostly trepostomes. Only five species are present; this is a surprisingly low diversity for such an abundant fauna. The fauna has been interpreted as indicating deep-water conditions (Anstey and Perry, 1972, p. 37, 38, 42, 44). The species documented here by Anstey and Perry (1972, p. 28, 35,49-52, 59-61, 63-75) are *Amplexopora septosa* (Ulrich, 1879) Cumings,

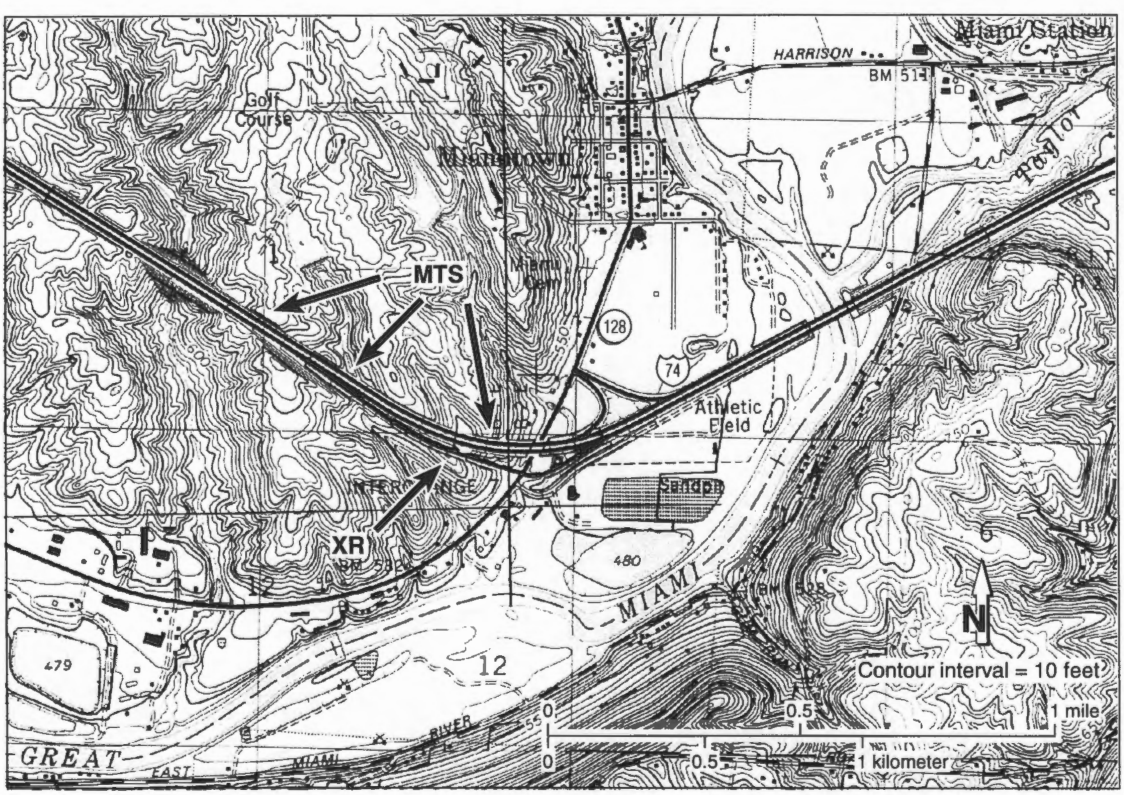

FIGURE 4-1.—Locations of the road cut in the Kope Formation at the Hamilton-Cleves exit ramp (OH-HA-0009; **XR** on map) and of the Miamitown Shale type section on north side of the Interstate (OH-HA-0008; **MTS** on map). Addyston, Ohio–Kentucky, 7.5-minute quadrangle.

FIGURE 4-2.—Bryozoan-rich strata of the upper Kope along the south side of Hamilton-Cleves exit ramp; photograph taken in 1988; the thicker bedded limestones in the upper part of the cut could be the Grand Avenue Member of the Kope Formation, although that unit reputedly pinches out east of this site (Ford, 1967).

1908, *Dekayia aspera* Milne-Edwards and Haime, 1851, *Hallopora nodulosa* (Nicholson, 1874) Anstey and Perry, 1973, *Heterotrypa ulrichi* Nicholson, 1881, and *Peronopora vera* Ulrich, 1888.

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Address of author: Roger J. Cuffey, Department of Geosciences (Deike Bldg.), Pennsylvania State University, University Park, PA 16802.

5. THE MAYSVILLE BRYOZOAN REEF MOUNDS IN THE GRANT LAKE LIMESTONE (UPPER ORDOVICIAN) OF NORTH-CENTRAL KENTUCKY

by
Roger J. Cuffey

Editor's note: Unfortunately, between 1992 and 1998, highway widening destroyed the part of the road cut that contained these unusual reef mounds. However, this paper is presented here as it was written in 1992.

SIGNIFICANCE

Two small reef mounds in the Grant Lake Limestone (upper Maysvillian) south of Maysville, Kentucky, were built almost entirely by the trepostome bryozoan *Stigmatella personata* Ulrich and Bassler, 1904. These Maysville bryozoan bioherms are significant because they represent one of the best developed and most accessible examples of bryozoan reefs known anywhere in the world and because they constitute a mode of bryozoan occurrence that is unique within the type-Cincinnatian.

Bryozoan reefs represent ecological extremes for their phylum and exotic rarities among bioherms in general (Cuffey, 1977, 1985, 1987). Only about 100 are known, especially from the mid-Ordovician, late Paleozoic, and mid-Cenozoic, and largely in North America and Eurasia; many are in remote or hazardous locations. In some, the importance of the bryozoans may be obscured by intermixture with animals of other phyla or by later development of diagenetic cements. As a result, the well-preserved, completely bryozoan, easily accessible (drive-up and park!) Maysville mounds are exquisite examples of these rare structures.

The type-Cincinnatian is famous for its bryozoan fossils, but none are reefal except for this Maysville occurrence, which is therefore of exceptional interest in the region. The normal mode of bryozoan occurrence is as broken branch fragments and small crusts or masses; all individual colonies are not interconnected, even though they may be abundant (Anstey and Fowler, 1969; Harris and Martin, 1979; Errett and Cuffey, 1989). Moreover, in contrast to the preceding epoch, the Late Ordovician in North America overall saw virtually no bryozoan reef construction; the only other instance known so far from this age is at Mullet Creek near Toronto, Ontario (Kobluk, 1980).

HISTORY OF STUDY

The Maysville bryozoan bioherms were first reported by Kissling and Turonis (1977). Later, their bryozoan species composition, constructional roles, reef-rock classification, and bryozoan reef type were noted (Cuffey, 1985, p. 309; Cuffey and Kamandulis, 1985). The Maysville mounds are under long-term detailed study (Roger A. Clark and Don L. Kissling, written communication, 1990).

LOCATION AND DIRECTIONS

The Maysville bryozoan reef mounds (KY-MS-0006) are two low limestone mounds, each about 3 meters (10 ft) wide by 0.3 meter (1 ft) high and separated by 2 meters (6 ft). They are exposed at road level in the ditch at the base of the 6-meter-high (20-ft) outcrop face on the west side of U.S. Route 68 0.1 mile (0.2 km) south of the junction of U.S. Route 68 and U.S. Route 62 at the south edge of the village of

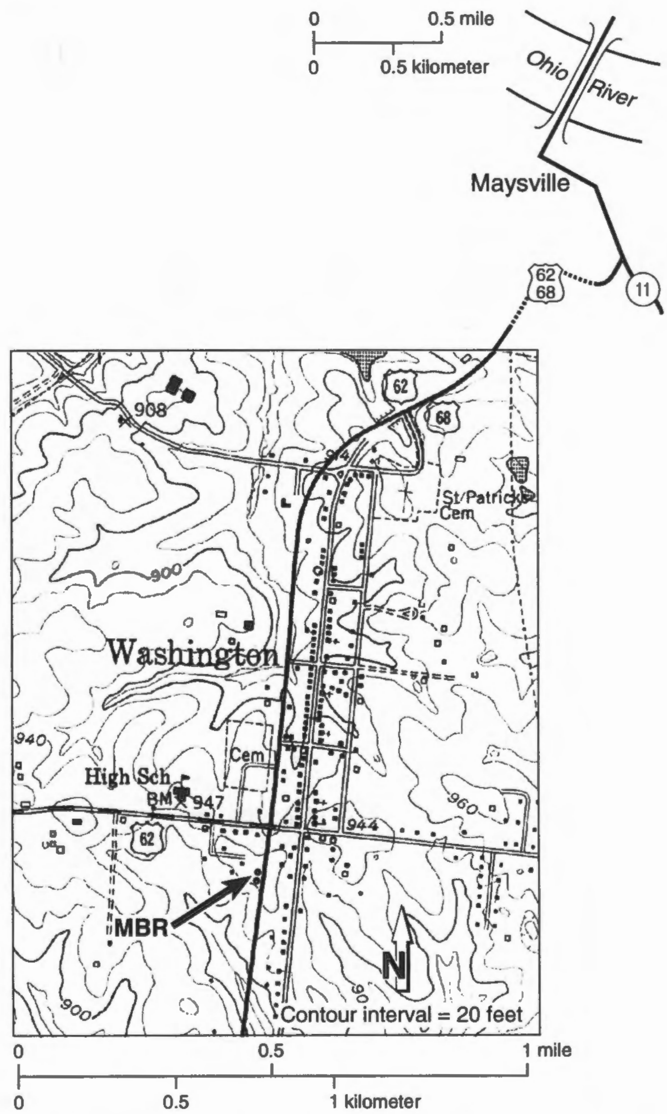

FIGURE 5-1.—Location of the Maysville bryozoan reef mounds (**MBR** and arrow). Topographic map is from Mays Lick, Kentucky, 7.5-minute quadrangle.

Washington, Kentucky (fig. 5-1). That junction is 5.0 miles (8.0 km) by road south of the southern end of the U.S. 68 bridge over the Ohio River at Maysville, or equivalently 4.3 miles (6.9 km) by road south of the junction of U.S. Route 68 and Kentucky Route 11 at the south-central edge of Maysville. One can park on the road shoulder next to the reefs; both the passing traffic and the roadside ditch must be avoided carefully. The condition of the ditch has varied considerably over the years; it was full of rubble which practically buried the reefs in 1982, but had been scooped out by 1984 and 1988 so that the reefs and their substratum were exposed as they had been in 1975 and 1976.

The Maysville bryozoan bioherms (or "bryoherms"; Cuffey, 1977, p. 185) are in Mason County, Kentucky, on the Mays Lick, Kentucky, 7.5-minute quadrangle (also available as a geologic quadrangle, Gibbons, 1968), at 38°36'36"N latitude and 83°48'39"W longitude (4277049 m N and 255255 m E, UTM zone 17). Neither section-township-range coordinates nor political township names are available for this part of Kentucky.

Note that the Maysville bryoherms are small, as well as quite unusual, and are under current study. Examination of these intriguing structures therefore should be cautious and conservation oriented in order to maximize their potential contribution to our understanding of bryozoans, reefs, and the type-Cincinnatian. At the same time, however, making these reef mounds readily available to visiting scientists also serves those goals; hence, this present brief paper.

STRATIGRAPHY AND REGIONAL PALEOENVIRONMENTS

The Maysville bryozoan mounds are stratigraphically within the upper Maysvillian, in the Grant Lake Limestone, approximately at the level of the Mt. Auburn-Corryville contact to the northwest (fig. 5-2) (Gibbons, 1968; Schilling and Peck, 1967; Don L. Kissling, written communication, 1984). The outcrop face above the reefs exposes rubbly, nodular, irregularly bedded limestone with minor shale partings characteristic of the upper member of the Grant Lake (Mt. Auburn equivalent). The reefs are founded upon a flat-bedded limestone and buried under a thin calcareous shale; such evenly bedded limestones with more shale beds characterize the middle member of the Grant Lake (Corryville equivalent). The lower member of the Grant Lake, equivalent to the Bellevue, is well below the road bed at the site of the reefs and not visible, but is rubbly limestone with little or no shale. The Mt. Auburn equivalent in the Maysville area has been renamed the Straight Creek Member by Schumacher and others (1991).

Five km (3 miles) northeast of this reef locality, essentially the same horizon as that of the mounds—the basal Mt. Auburn or Straight Creek—carries massive bryozoans, including the same genus which is dominant here (Schmidt and others, 1961, p. 272-273, 279-280), but they are not developed into biohermal accumulations. Similar colonies but not bioherms also were noted there by those authors at a lower horizon, the basal Corryville or topmost Bellevue. Likewise, no additional bryozoan bioherms thus far have been found at either horizon within several kilometers from the reef-mound locality, in spite of extensive searches by both Kissling and Cuffey.

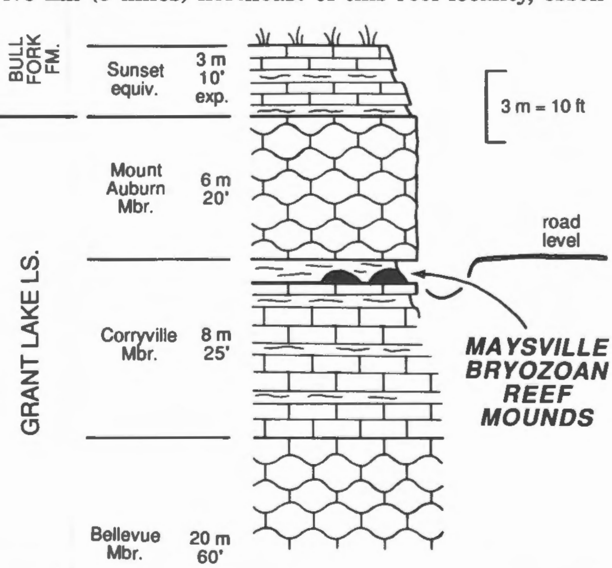

FIGURE 5-2.—Stratigraphic succession containing the Maysville bryozoan reef mounds. Nomenclature and lithologic symbols after Gibbons (1968) and Schilling and Peck (1967); the Mt. Auburn Member is the Straight Creek Member of Schumacher and others (1991). Unit thicknesses were derived from elevations of contacts mapped on Gibbons (1968) at and near the location of the reefs.

As noted in the introductory paper for this volume (Cuffey, paper 2), stratigraphic correlations and inferred paleoenvironments of the type-Cincinnatian can be coordinated and summarized as background specifically for bryozoan investigations. Plotting the environments indicated by the rock types of the formations correlated with the horizon of the Maysville bryoherms yields a regional cross section or profile (fig. 5-3) within which the reef mounds can be seen in broad paleoenvironmental context: out on a tropical, shallow, offshore, carbonate platform, flanked by deeper, muddy-bottomed water farther offshore to the northwest.

REEF-MOUND CHARACTERISTICS AND LOCAL PALEOECOLOGY

REEF-MOUND GEOMETRY

Both mounds are bisected by the vertical face of the outcrop and so reveal their cross-sectional shape well but not much of their plan views. Overall, each appears as a low, wide, partially flat topped dome (fig. 5-4), with a possibly circular, oval, or even irregular outline horizontally. When measured in 1984, following at least one burial and re-exposure by highway-department road-ditch scraping, the outcrop had been cut back enough to show the reef mounds well (figs. 5-5A, 5-5B); the southern mound then was 3 meters (10 ft) wide at its base, the northern one 3.4 meters (11.2 ft) wide, and both only 0.3 meter (1.0 ft) high. In life, therefore, the mounds would have appeared as low rocky rises several cm above the surrounding shallow sea floor, whether muddy or hardground.

Such low relief over the reef mounds is not likely to represent the total water depth around the mounds during their growth, especially because the tops of the mounds show no effects of having been battered by surf action. Instead, note that the living Bahamian bryozoan reefs (Cuffey and others, 1977), which are roughly similar in size to the Maysville ones, lie under 3-4 meters (10-12 ft) of water even at low tide, a depth which has also been suggested for the Cincinnatian lithofacies enclosing the mounds from regional paleoenvironmental interpretations (Cuffey, paper 2 in this volume).

REEF-ROCK CHARACTERISTICS

The Maysville bioherms are massive to nodular limestones, even viewed from a distance, but appear quite different from the typical Cincinnatian limestone layers all around them. Close examination reveals that the bioherms consist of very large, solid, tubulobryozoan crusts, masses, and domes, overgrowing and attached one atop another (figs. 5-5C, 5-5D, 5-6A, and 5-6B). In places, they are tightly cemented to each other; in others, they are only loosely attached, because of an intervening thin film of mud. Thus,

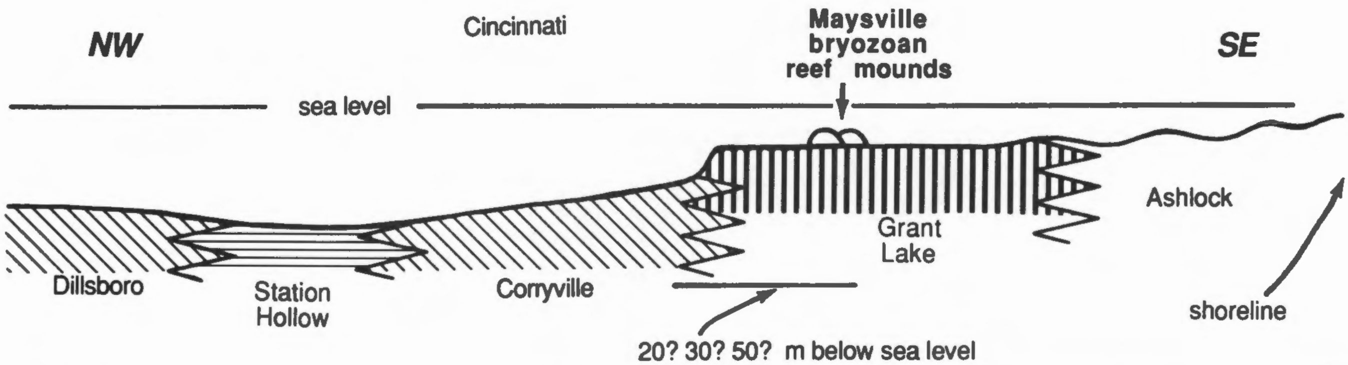

FIGURE 5-3.—Generalized paleoenvironmental profile across the Cincinnati region at the time of growth of the Maysville bryozoan reef mounds. The scale is approximate. Lithofacies and paleoenvironments from figure 2-2 and correlations from figure 2-4 of Cuffey (paper 2 in this volume).

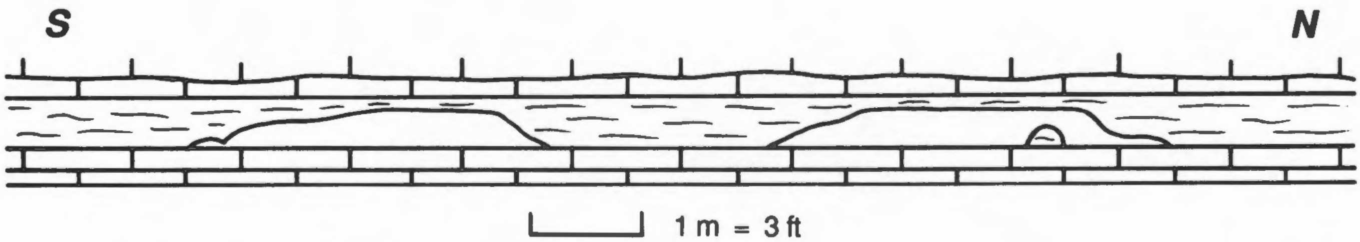

FIGURE 5-4.—Vertical cross section of the two Maysville bryozoan reef mounds, as measured by Cuffey and Kamandulis in 1984; no vertical exaggeration.

the biohermal rock ranges from solidly massive to rubbly nodular along the exposure. In the expanded petrographic reef-rock and reef-type classification of Cuffey (1985), the Maysville bryozoan bioherms are crust mounds composed of trepostome globstones and cruststones. They exemplify the reef-constructional role of principal frame building by bryozoans alone (Cuffey, 1977).

The individual colonies vary greatly in size, but the majority are 5-20 cm wide by 1-4 cm high. Maximum observed size is 95 cm across and 15 cm thick (Kissling and Turonis, 1977; Don L. Kissling, written communication, 1984). Broken surfaces of colonies appear finely striated, due to the thin, elongate, tubular zooecia. The broken colonies range from light gray to pink or white, in contrast to the medium or dark gray of the surrounding thin-bedded limestones and shales. Many successive colonies are separated by thin dark-gray bands; these consist of the mud-filled, distal ends of the zooecial tubes immediately below an exterior or upper growing surface, which had received a dusting of detrital sediment before being overgrown by the next colony.

In a few places within each mound, the edges of the bryozoan colonies curve or bend away from each other, thus creating small, irregular growth cavities inside the reefs. These cavities are now filled with detrital mud that contains a few little rhynchonellid brachiopods which originally might have lived in the cavities or might have been washed in after death. Unlike many reef cavities elsewhere, the walls and roofs of these cavities are bare; only the primary frame-building bryozoans are visible, and they are not encrusted by other bryozoans or animals of other phyla. This lack of a coelobitic, cavity-dwelling fauna suggests that mud filled the cavities as fast as the reefs grew (Kissling and Turonis, 1977).

The Maysville reefs appear to be essentially homogeneous throughout their extent; they do not exhibit any vertical or lateral ecozonation. This lack of zonation probably is due to their small size; they simply were not large enough to develop different growing conditions across their surfaces, nor to influence water movements and physical sedimentation around them.

BRYOZOAN FRAME BUILDERS

A hundred reef-rock samples were collected according to a uniformly rectangular grid across both mounds. Each sample contained several bryozoan colonies. Every sample was sectioned in order to identify the species responsible for building the Maysville bryoherms (Cuffey and Kamandulis, 1985). Only two species were found, both trepostomes.

One species is overwhelmingly predominant, constituting 98 percent of the reef-mound frame builders: *Stigmatella personata* (figs. 5-6C and 5-6D). It occurs as small to very large colonies of crustose, tabular, lenticular, domal, hemispherical, and massive forms. These all consist of zooecia packed tightly together without any intervening mesopores. The zooecia are elongate, prismatic, and thin walled, and have polygonal, angular apertures and a few tiny obscure acanthorods. The zooecia appear mostly empty, but some are crossed in places by a few diaphragms. Considerable morphologic variability is displayed among the many colonies, but extreme variants which might be misidentified as other species are all interconnected with the typical population by continuous series of intermediates. This species was described thoroughly by Cumings (1908, p. 884, pl. 24, fig. 3-3d) and by Utgaard and Perry (1964, p. 82-85, pl. 15, fig. 3-8, pl. 16, fig. 1-4). It was known previously from the Whitewater Formation down into the Waynesville Formation, so its presence at this locality represents a slight range extension downward. It has been suggested that delayed maturation due to a medical-type heterochronic mutation within the local population of this species may have been responsible for development of these Maysville reefs (Cuffey and Pursell, 1995).

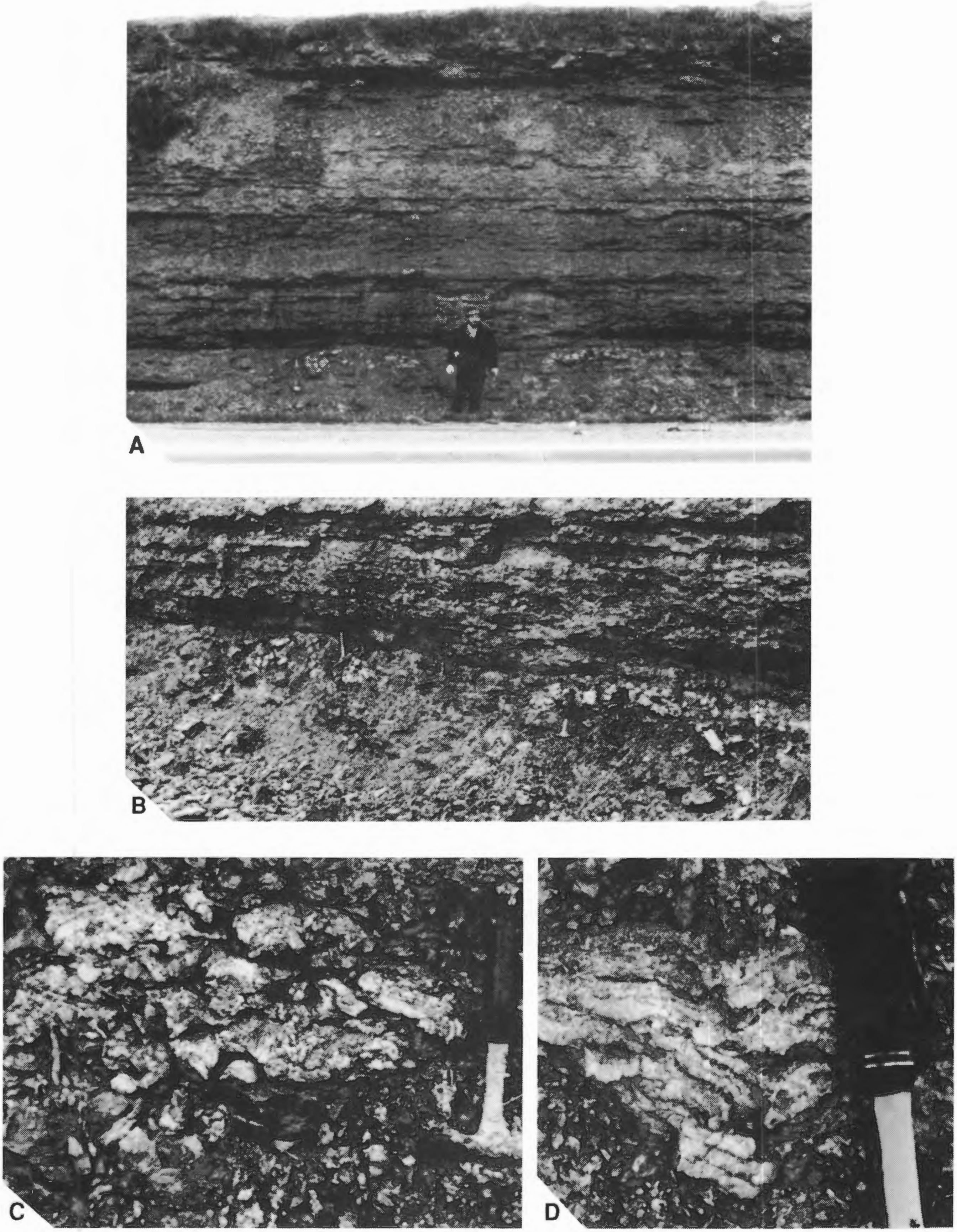

FIGURE 5-5.—Photographs of the Maysville bryozoan reef mounds taken in 1984. **A**, at the base of the vertical outcrop face, Michael Kamandulis between the mounds; **B**, from the road ditch, a geologic hammer on each mound (southern mound on the left in both **A** and **B**); **C**, bryozoan globstone; and **D**, bryozoan cruststone, in place in the field (hammer for scale in both **C** and **D**).

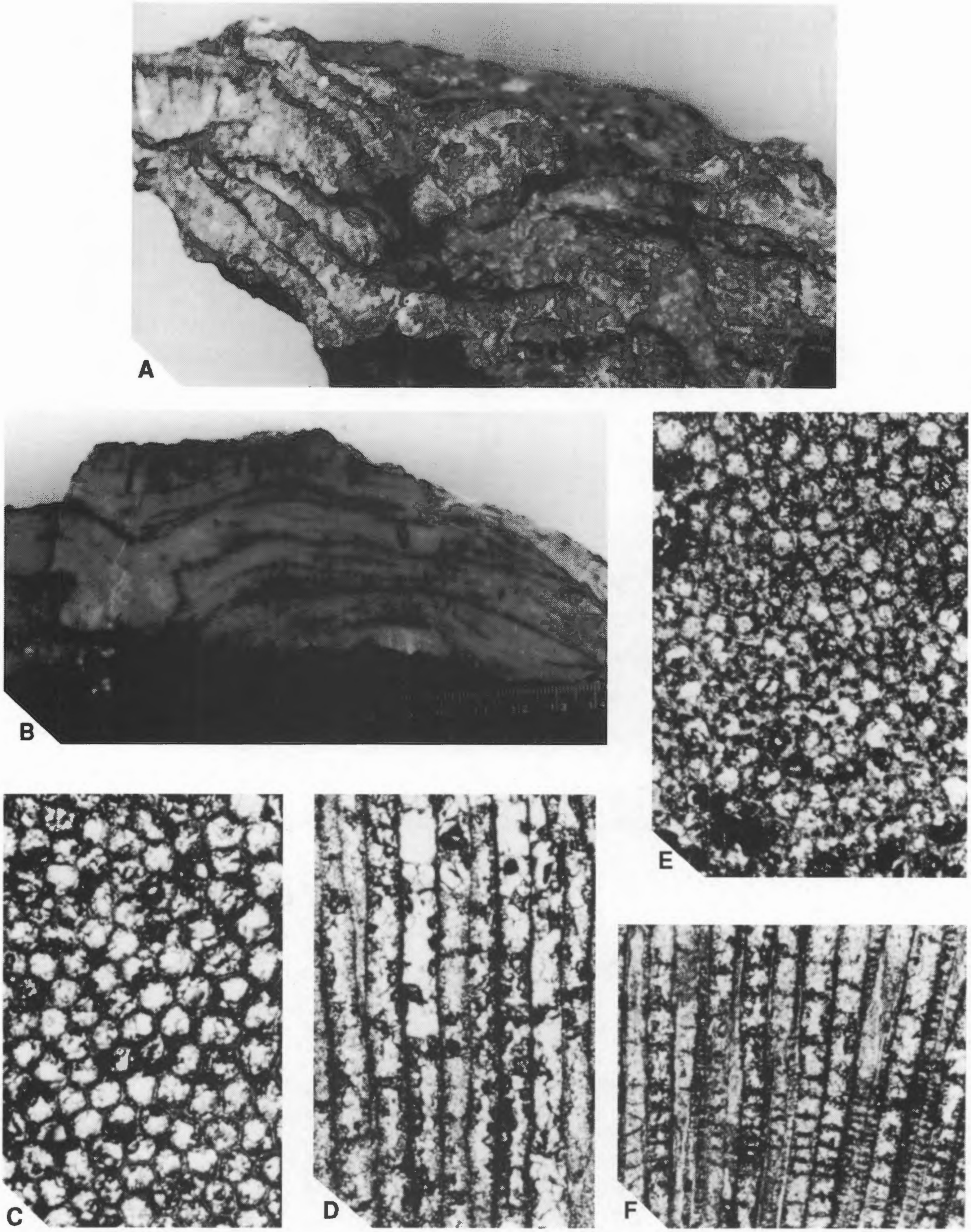

FIGURE 5-6.—Maysville bryozoan reef rock and reef-building species; **A**, vertically broken surface, and **B**, polished surface of bryozoan cruststone pieces (ruler in cm and mm); **C**, **D**, *Stigmatella personata* (the dominant species) in tangential and longitudinal peel sections; **E**, **F**, *Atactoporella mundula* (the rare species) in tangential and longitudinal peel sections; figured sections (all X29) are in the KETMAS-1 suite (S5b, S12c, S7u, S7u, respectively) in the Paleobryozoological Research Collection at Pennsylvania State University.

A few thin encrusting colonies, only 2 percent of the reef-mound frame builders, represent *Atactoporella mundula* (Ulrich, 1879) Ulrich, 1883 (figs. 5-6E and 5-6F). Its zooecia are cylindrical and thin walled, and have round apertures, numerous large acanthorods, and some diaphragms. Large, angular mesopores containing many closely spaced diaphragms are packed in among the zooecia. Cumings (1908, p. 770, pl. 7, figs. 3-3a, pl. 26, fig. 6) and Brown and Daly (1985, p. 25, pl. 1, figs. 9-12) furnished additional descriptive data. This species has been found from the Bellevue Member of the Grant Lake Formation up through the Arnheim Formation, a range that includes the stratigraphic level of the present locality.

The extremely low biodiversity shown by the frame builders of the Maysville reefs is surprising, especially in view of the great number of bryozoan species in the type-Cincinnatian overall. Bryozoans in contemporaneous rocks surrounding the Maysville reefs (Pursell and Cuffey, 1995) are highly diverse and comprise abundant, normal-sized, isolated colonies, with well-developed mature exozones. Species identified are mostly trepostomes (the monticuliporids *Monticulipora mammulata**, *Atactoporella mundula**, *Homotrypa grandis*, *H. nodulosa*, *Homotrypella hospitalis*, *Peronopora decipiens**, *P. dubia*, and *P. pachymura**; the heterotrypids *Heterotrypa frondosa**, *H. solitaria*, *Dekayia aspera**, *D. inflecta*, *D. magna*, *D. mesospinosa*, and *D. prolifica*; the diplotrypid *Batostoma* sp.; the amplexoporids *Amplexopora cingulata*, *A. filiasa**, *A. parva*, and *A. winchelli*; the halloporids *Parvohallopora ramosa** and *P. rugosa**; and the batostomellid *Bythopora dendrina**) plus one ceramoporoid (*Ceramopora invenusta**). In addition, a few broken fragments of the reefs' principal frame builder, the heterotrypid *Stigmatella personata**, were found north and east of the reef mounds, suggestive of prevailing currents of the kind expected in such shallow-water habitats as that represented here. Many of these species—those marked with an asterisk (*)—also occur in the rock immediately underlying the reefs, as do the monticuliporid *Homotrypa flabellaris*, the heterotrypid *Leptotrypa minima*, the diplotrypid *Batostoma implicatum*, and a halloporid transitional between *Parvohallopora ramosa* and *P. subnodosa*. The few specimens of *Stigmatella personata* (the principal frame builder in the reefs) that have been found beneath the reefs are dome shaped, but normal sized, giving no hint of the reef building of the species to come. Moreover, this predominant frame-building species has been found in the region, but only as normal-sized colonies occurring individually rather than in biohermal accumulations. Recall, too, that very few bryozoan reefs are known from the North American Upper Ordovician. In our present state of incomplete knowledge concerning bryozoan reefs worldwide through time, possible explanations for such observations remain only speculative. (Note that *Parvohallopora ramosa* and *P. rugosa* may be conspecific; their distributions do overlap, but they do not coincide. It is important to record each variant wherever it turns up, because that eventually may tell us what each was. For example, perhaps the variants are a reflection of local variation in microhabitat.)

SURROUNDING SEDIMENTS

Reef foundation

The Maysville bryozoan bioherms arise from a well-indurated, calcarenitic limestone bed, 0.1 meter (0.3 ft) thick. The upper surface of the limestone apparently was a rocky, solid hardground by the time the bryozoans began to encrust it. That surface is ferruginous in places, obscurely ripple marked in others, and extensively perforated by narrow, cylindrical, vertical borings 2-4 mm in diameter. The fact that some of those borings are directly covered by bryozoan colonies at the base of the reefs confirms that the original lime sands had lithified enough to support such borings without collapsing before encrustation by the bryozoans. Kissling and Turonis (1977) thought that the hardground might have been relatively local and that its limits might have controlled the plan-view outlines of the Maysville bryoherms. However, the same foundation bed is exposed roughly 30 meters (100 ft) away on the other side of the road, but there lacks any biohermal development, although a few small zoaria of the dominant species occur widely scattered across its upper surface. The hardground also extends well beyond the edges of the mounds on the west side of the highway, although its degree of development there does vary considerably.

Among bryozoan reefs so far known, a majority are founded on sand-textured substrates (Cuffey, 1987), but a few are on surfaces that were clearly already lithified as a hardground like here.

Below the hardground surface, the foundation bed is dark-gray grainstone composed of finely comminuted shell fragments that are flat or flake shaped, lie parallel to bedding, and are spar cemented. This bed in turn is underlain by characteristic Cincinnatian limestones and shales.

Lateral flanks

As seen in the outcrop along the west side of the highway, thin-bedded limestones and shales are laterally adjacent to the Maysville bryoherms and occupy the same interval. Approaching the low-domed reefs, several thin limestone beds bend slightly upward into a flanking dip of about 10°. Some of this dip may have been original depositional dip, some may result from postburial compactional drape over the solid mounds, but how much is due to each cause is unclear. Immediately adjacent to the bioherms are mostly shaly mudstones, within which continuous bedding planes are so difficult to follow that the geometric relationships between the reef rock and the flanking sediments remain obscure. Thus, it is uncertain whether the reef mounds during life were surrounded by accumulating soft muds or by the bare rock surface of the underlying hardground. Clarification of these relationships is one goal of the continuing studies of this site.

The sediments around the mounds have yielded only one or two eroded cobbles of the bryozoan reef rock and no broken fragments of the frame-building species. These small bryozoan reefs thus did not contribute any significant quantity of bioclastic debris to the surrounding sea floor.

Overburden

The two Maysville reef mounds are overlain by dark-gray shaly mudstone that is calcareous but relatively unfossiliferous. Influx of this detrital sediment, whether quickly as a result of storm activity or more slowly as a consequence of increased runoff from far-away land masses, smothered and thereby terminated reef growth here. A majority of other known bryozoan reefs likewise met their ends due to the smothering effect of burying muddy sediments (Cuffey, 1987).

This overlying mudstone in turn is succeeded by the usual type-Cincinnatian thin-bedded limestones and shales, well exposed in the outcrop face above the bryoherms.

REEF DURATION

The length of time necessary for the Maysville bryozoan reefs to grow to their observed size can be estimated from two lines of evidence. First, normal-sized, robust bryozoan colonies have lifespans of several years, unusually large ones probably as much as several decades; hence, a succession of several such colonies encrusting upon one another quite possibly would represent several centuries or a millenium or two of growth. Second, the three known living bryozoan reefs—of roughly comparable size to the Maysville structures—have growth durations of several centuries or a millenium as determined from radiocarbon dating or historical records: Joulters Cays in the Bahamas, almost 1,000 years (Cuffey and Fonda, 1979); coastal Netherlands, about 300 years (Bijma and Boekschoten, 1985); and Coorong Lagoon in Australia, 700 years (Bone and Wass, 1990). Consequently, the Maysville bryoherms probably represent growth on the order of a thousand years or so.

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Address of author: Roger J. Cuffey, Department of Geosciences (Deike Building), Pennsylvania State University, University Park, PA 16802.

6. THE MADISON/U.S. ROUTE 421 ROAD CUTS—BELLEVUE THROUGH UPPER WHITEWATER STRATA (UPPER ORDOVICIAN, SOUTHEASTERN INDIANA)

by
Helen B. Hay, Stanley M. Totten, and Roger J. Cuffey

SIGNIFICANCE

The Ordovician outcrops at Madison, Indiana, are among the classic Cincinnatian fossil-collecting localities of the Ohio-Kentucky-Indiana tri-state area. "In addition, the distinctive dolomitic and sparsely fossiliferous Saluda Formation near the top of the Ordovician is well exposed and reaches its maximum thickness in the Madison area." (Totten and Hay, 1987, p. 365). Relatively recent road cuts along U.S. Route 421, north from the east side of Madison, expose the upper part of the Cincinnatian and provide significant insight into the stratigraphy of those units. The outcrops here can be compared instructively to those seen along Indiana Route 56 a few miles to the southwest (Hattin and Cuffey, paper 14 this volume). The Ordovician-Silurian contact, overlain by about 7 meters (23 ft) of Silurian rock, is exposed in the northernmost outcrop along U.S. 421.

LOCATION

This locality consists of three road cuts along U.S. Route 421, at various distances south from its junction with Indiana Route 62 and over 3 miles (4.8 km) north of historic downtown Madison, Jefferson County, Indiana (fig. 6-1). These localities were referred to as the north, middle, and south road cuts, respectively, by Totten and Hay (1987) and given letter designations in their locality map (Totten and Hay, 1987, fig. 1):

Madison North road cut (= their A), 0.2-0.7 mile (0.3-1.1 km) south of intersection;
Madison Middle road cut (= their B), 1.1-1.2 miles (1.8-1.9 km) south of intersection; and
Madison South road cut (= their C), 2.8-2.9 miles (4.5-4.6 km) south of intersection.

The massive Saluda Dolomite is nicely exposed in the north cut 0.5 mile (0.8 km) south of that junction. The north road cut (IN-JE-0001) occupies the SW corner sec. 13 and NW$\frac{1}{4}$NW$\frac{1}{4}$ and center NW$\frac{1}{4}$ sec. 24; the middle road cut (IN-JE-0002) is in the center SW$\frac{1}{4}$ sec. 24; and the south road cut (IN-JE-0003) is in the center W$\frac{1}{2}$NE$\frac{1}{4}$ sec. 35; all are in T. 4 N., R. 10 E., the first two on the Canaan, Indiana, 7.5-minute quadrangle, the third on the Madison West, Indiana–Kentucky, 7.5-minute quadrangle. The Saluda exposure is located at 38°46'45"N, 85°21'58"W (4293308 m N, 641928 m E, UTM zone 16).

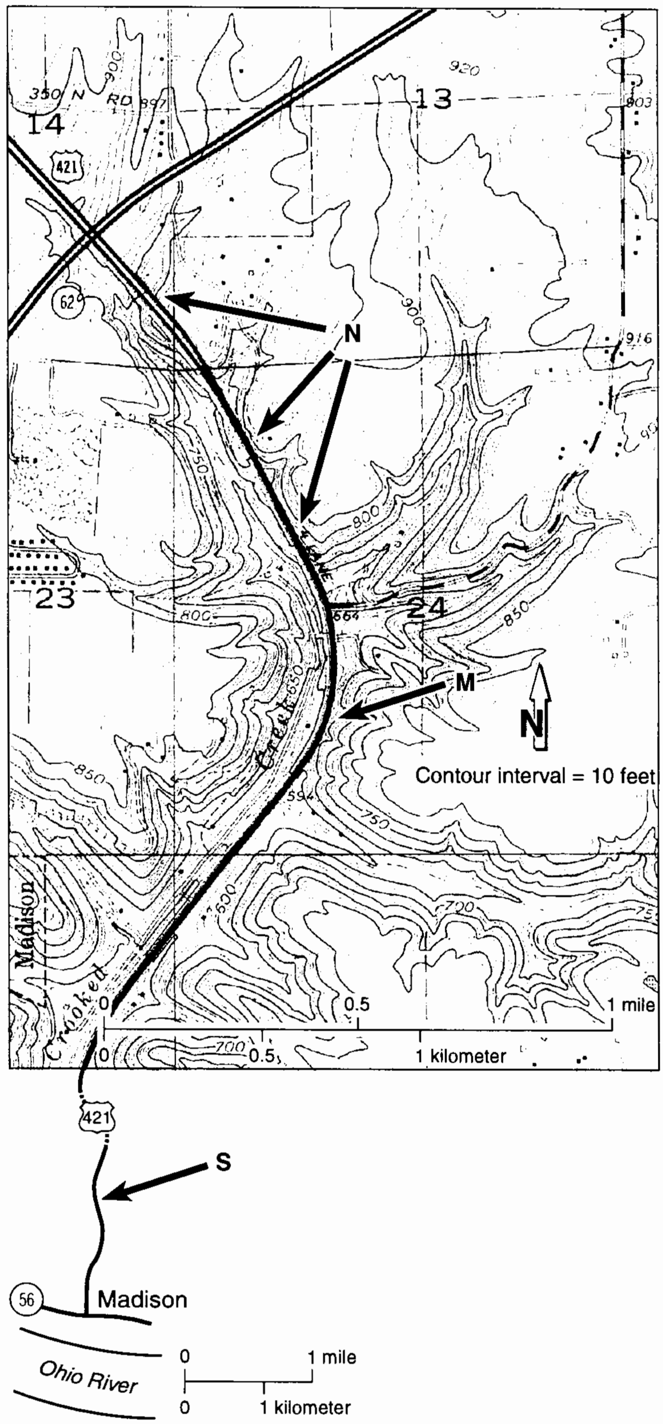

FIGURE 6-1.—Location of the U.S. Route 421 road cuts (**N**, **M**, **S** = north, middle, and south cuts, respectively). The three **N** arrows indicate (from north to south) the northern end of the north cut, the Saluda outcrop, and the southern end of the north cut. Topographic map is from the Canaan, Indiana, 7.5-minute quadrangle.

STRATIGRAPHY

The Madison/U.S. Route 421 road cuts have been described by Totten and Hay (1987). The following discussion of the stratigraphy is only slightly altered from that work.

Cincinnatian rock-stratigraphic classification for southeastern Indiana and southwestern Ohio has undergone substantial revision during the past 30 years. Hay (1981) and Hay and others (1981) extended the Fairview, Miamitown, and Bellevue formation names throughout the outcrop area of Indiana and Ohio and named a new unit, the "Brookville formation," for strata between the top of the Bellevue and the base of the Saluda or Whitewater Formation. The "Brookville formation," equivalent to the upper part of the Dillsboro, is divided into five members, three of which occur in the Madison area. Hay (fig. 17-3 in paper 17 of this volume) compares these new units with previous rock-stratigraphic classifications.

All of the Cincinnatian Series of Ohio and Indiana, with the exception of the Saluda, consists of interbedded thin- to medium-bedded fossiliferous limestones and thin to thick calcareous shales. The limestones include a variety of types (Martin, 1975), but the most common is biomicrosparrudite. Lithofacies are distinguished by percentages of shale, bedding characteristics, textures and structures of the limestones, and character of the shales, including the presence or absence of conspicuous lenses and/or nodules of limestone in the shales (referred to as limy shales).

Six lithofacies types occur in the Madison road cuts: 1a, 2a, 2b, 3a, 3b, and 3c (fig. 6-2). See Hay (paper 17 in this volume) for fuller discussion of these lithofacies, which are summarized here in figure 6-3. The numbers 1, 2, and 3 of the first part of the facies code refer to shale percentage: 1 = greater than 70 percent shale; 2 = 55 to 70 percent; and 3 = less than 55 percent. The second part of the facies code refers to other stratigraphic and lithologic aspects: the letter "a" indicates rather even-bedded limestones and shales without limestone lenses and/or nodules; "b," well-bedded limestones interbedded with limy shales, although some of the limestone beds of these facies may be argillaceous and rubbly; and "c," poorly bedded, rubbly, argillaceous limestones and very limy shales sueh that a given bed may be called either argillaceous limestone or limy shale.

Cincinnatian strata are exposed in each of the three road cuts along U.S. Route 421 north of Madison (fig. 6-2). The southernmost section, 0.5 mile (0.8 km) north of Madison, includes the upper 7.6 ft (2.3 meters) of the Bellevue Limestone and about 99 ft (30 meters) of the "Excello member" of the "Brookville formation." Toward the north is a small road cut which exposes 16 ft (4.9 meters) of the "Excello member." This section overlaps the top of the south road cut and is close to the top of the "Excello member." The Waynesville Shale Member lies in a covered stratigraphic interval of about 60 ft (18.3 meters) between the top of the middle road cut and the base of the long road cut just to the north. The third and northernmost road cut exposes the Liberty Member of the "Brookville formation," the Saluda and Whitewater Formations, and the Silurian formations.

The Cincinnatian fauna includes abundant and diverse representatives of many phyla. The major rock formers are bryozoans, brachiopods, echinoderms, and mollusks. Trilobites are common, and corals occur in the upper part of the section. Ostracodes are abundant in parts of the Saluda. An excellent and inexpensive reference for identification of these and many other Ordovician fossils is available (Davis, 1992).

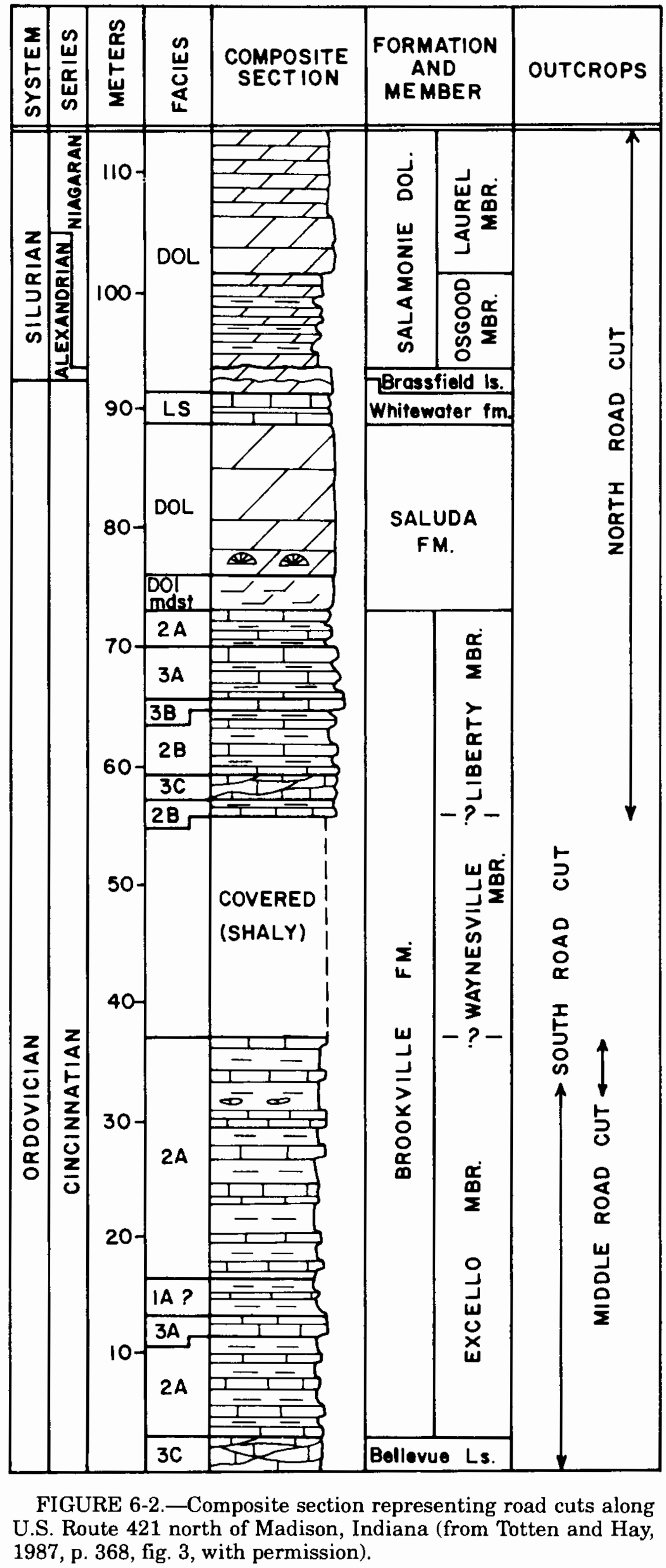

FIGURE 6-2.—Composite section representing road cuts along U.S. Route 421 north of Madison, Indiana (from Totten and Hay, 1987, p. 368, fig. 3, with permission).

BELLEVUE LIMESTONE

The Bellevue Limestone is approximately 40 ft (12 meters) thick in the Madison area, but only the top 7.6 ft (2.3 meters) are exposed in the south road cut, where it is assigned to rubbly facies 3c (fig. 6-2). Notable fossils include the brachiopods *Platystrophia ponderosa*, *P. laticosta*, *Hebertella sinuata*, *Plectorthis*, and *Rafinesquina*; *Rafinesquina* occurs throughout the Cincinnatian. Massive and encrusting bryozoans and *Parvohallopora*, a genus of dendritic bryozoans, are major faunal components.

The Bellevue was probably deposited in very shallow, slightly agitated, normal-marine water. The fine-grained terrigenous clastics were not winnowed out, and the envi-

Principal diagnostic characteristics of lithofacies

Group 1 >70% shale	1a	Well-bedded, mostly thin limestones and medium to thick, fissile to blocky shales. Includes massive units of 100% shale. Low-diversity fauna.
	1b	Rubbly, shaly, nodular limestones; medium to thick shales with limy stringers and layers of fossils in shale matrix. May have some well-bedded limestones as in 1a. Low-diversity fauna. Most easily seen in cores.
Group 2 55-70% shale	2a	Like 1a except has high diversity of fauna. Intermediate in shale percentage between 1a and 3a.
	2b	Well-bedded limestones, rubbly nodular limestones, and limy shales. Allochems tend to be more finely broken than 2a. High-diversity fauna. Intermediate between 3a and 3c.
Group 3 <55% shale	3a	Well-bedded, thin to medium limestones and thin to medium, fissile to blocky shales. High-diversity fauna.
	3b	Well-bedded, thin to medium limestones with or without rubbly or nodular shales. High-diversity fauna. Intermediate between 3a and 3c.
	3c	Thin-bedded, rubbly weathering, argillaceous limestones, very thin limy shales. High-diversity fauna.
	3d	Limestones and shales as in 3a except >20% of limestones are fine-grained laminated burrowed, barren of large fossils; trails on tops. Grade to siltstones.
Group 4 Miscellaneous	4a	High-angle cross-bedded calcarenites, bimodal dip. Little or no shale.
	4b	Granule-size fossils in thick to massive beds; little or no shale. May be like 4a if seen in similar outcrops.
	4c	Massive *Loxoplocus* limestone bed. Marble Hill Bed.
	4d	Bioturbated light-gray limestone with low-diversity fauna of ostracodes, algae, snails, and *Tetradium*. Related to Saluda facies complex.

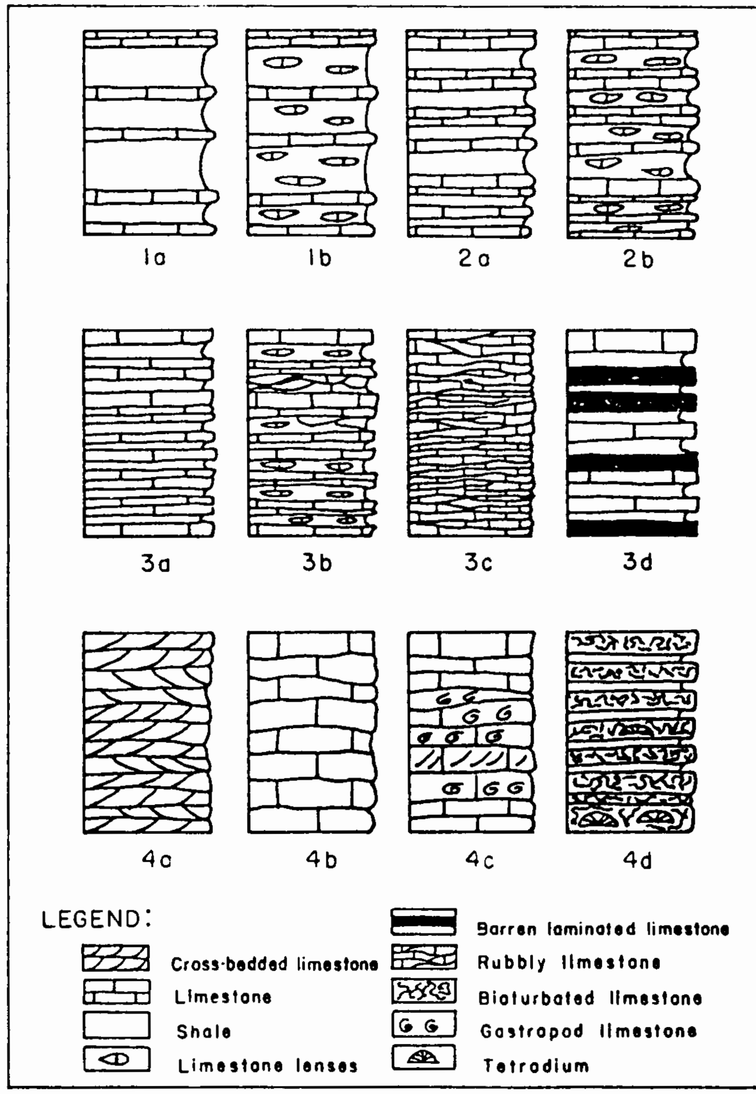

FIGURE 6-3.—Lithofacies characteristics (see Hay, paper 17 in this volume).

ronment, therefore, was not likely to have been one of extremely high energy.

"EXCELLO MEMBER" OF THE "BROOKVILLE FORMATION"

The "Excello member" constitutes the remainder of the south road cut and the middle road cut. As figure 6-2 indicates, the "Excello" is composed of intervals of facies 1a, 2a, and 3a. Most of the outcrop by far is classified as facies 2a but could be more finely subdivided into smaller intervals of 3a alternating with 1a. Compared with the Bellevue, the limestones are generally thicker and more evenly bedded, and the shales are fissile or blocky, not limy. The south road cut has four levels separated by three benches. *Platystrophia ponderosa* and *P. laticosta* are found as high as the second level but not higher. Other brachiopods are *Rafinesquina*, *Zygospira*, and *Plectorthis*; *Leptaena* occurs in level three. The "Excello" has abundant and diverse mollusks. *Ctenodonta*, a small clam, is particularly abundant at the top of the middle road cut. Large, coarse-ribbed clams, gastropods, including *Cyclonema inflatum*, and cephalopods also occur. Echinoderms, bryozoans, and trilobites occur in the "Excello."

The "Excello" sediments indicate a transgressive phase with sediments deposited in slightly deeper water than the Bellevue, probably below normal wave base but subject to periodic reworking by storm waves and strong currents that accounted for the interbedding of limestones and shales. Martin (1975) and Harris and Martin (1979) believed that the limestones are in situ biogenic accretions representing progressive community development after colonization of the muddy substrate.

LIBERTY MEMBER OF THE "BROOKVILLE FORMATION"

The lower half of the Liberty Member (fig. 6-2), exposed at the base of the north road cut, consists of several facies intervals (2b, 3c, 2b, 3b upward), which vary in shale percentage but share the characteristic of limy shales. Except for a generally higher percentage of shale, these intervals are similar to the facies of the Bellevue and probably represent a similar depositional environment. The upper half of the Liberty Member has more limestone than the lower half and has nonlimy shales. These upper beds were probably deposited in a higher energy environment close to normal wave base. The Liberty-Saluda sequence indicates shoaling of the sea, a regressive phase. Prominent Liberty brachiopods include *Thaerodonta*, *Plaesiomys*, *Hebertella*, *Rafinesquina*, *Catazyga*, *Strophomena*, and *Hiscobeccus*. The horn coral *Grewingkia* is present.

SALUDA FORMATION

The Saluda contains a number of facies but is distinguished from the other formations by the preponderance of fine-grained dolomite and dolomitic mudstones, having lesser amounts of dolomitic limestone in the upper and lower parts. The base consists of 7.5 ft (2.3 meters) of slabby dolomitic mudstone that appears quite massive in fresh cuts. This lithology is overlain by interbedded limestone, dolomite, and mudstone containing the large colonial corals *Favistina* and *Tetradium*. The thickest unit of the Saluda is mud-cracked and ripple-marked, argillaceous and silty dolomite that exhibits color mottling in its lower part. This laminated, rather homogeneous rock appears massive in the fresh road cut. The total thickness of the Saluda is 51 ft (15.5 meters).

The main body of the Saluda is nearly barren of fossils, but some beds and bedding planes bear a normal-marine fauna that perhaps was washed into the area or that may indicate times of normal-marine salinity. Ostracodes and burrows are the dominant fossils in the lower and upper dolomitic and calcareous zones. Hatfield (1968) interpreted the paleogeographic setting of the Saluda as a hypersaline lagoon rimmed by colonial coral reefs, a couple of which are exposed in these road cuts (Laribee, 1994). The mud-cracked sediment was intermittently exposed to the atmosphere. Regionally, it is a lens-shaped body of rock that pinches out northward between Brookville and Richmond, Indiana (Hay, 1981). The Saluda is time equivalent to the mid-Whitewater strata to the east at Caesar Creek, where the bryozoans are highly diverse (Rockwell and Cuffey, 1996; Schumacher and others, paper 13 of this volume) and thus contrast with the greatly reduced bryozoan fauna here and associated with the penesaline Saluda shelf lagoon (Butler and Cuffey, 1994, 1996; Cuffey, Butler, and Rockwell, 1996).

UPPER? WHITEWATER FORMATION

The Whitewater Formation is 12.5 ft (3.8 meters) thick at Madison, if, as we consider it here, the base is taken to be at the change from Saluda dolomite to dolomitic limestone. If the *Lophospira hammelli* bed is taken as the base of the Whitewater (Foerste, 1903), the Saluda is 59.4 ft (18 meters) thick and the Whitewater is 4.6 ft (1.4 meters) thick at Madison. The Whitewater lithology farther north in Indiana is typically that of rubbly facies 3c, but at the road cut at Madison it consists, in descending order, of the following six units (modified from Conklin, 1977) that do not fit the facies classification used for other Ordovician strata: (1) fine-grained mottled dolomite (1.8 ft/0.56 meter), (2) black shale (2.56 inches/6.4 cm), (3) fossiliferous micritic limestone with the gastropod *Lophospira hammelli* (2.9 ft/0.87 meter), (4) black shale (0.2 inch/0.4 cm), (5) silty dolomitic biomicrosparite with ostracodes (9 inches/22.9 cm), and (6) ostracode-bearing, coarse-grained, greenish-gray, burrowed dolomitic limestone (8 ft/2.44 meters) placed by some authors at the top of the Saluda rather than in the Whitewater.

The Whitewater represents a return to normal-marine conditions, although the origin of the fine-grained dolomite at the top is uncertain.

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Addresses of authors: Helen B. Hay, deceased, formerly Geology Department, Earlham College, Richmond, IN 47374; Stanley M. Totten, Department of Geology, Hanover College, Hanover, IN 47243; and Roger J. Cuffey, Department of Geosciences (Deike Bldg.), Pennsylvania State University, University Park, PA 16802.

7. THE MIAMITOWN SHALE: STRATIGRAPHIC AND HISTORIC CONTEXT (UPPER ORDOVICIAN, CINCINNATI, OHIO, REGION)

by
Benjamin F. Dattilo

INTRODUCTION

In 1958, Gutstadt observed that the original stratigraphic nomenclature of the Cincinnatian rocks (for example, Nickles, 1902) was defined by a mixture of paleontologic and lithologic criteria. He concluded that it was necessary to separate lithostratigraphic and chronostratigraphic terminology for these strata. This sentiment was an important factor in the development of new lithostratigraphic units to replace the old, largely biostratigraphic units.

More recent studies, however, indicated the possibility that eustatically induced lithologic cyclicity is present in the Cincinnatian (Tobin, 1982; Jennette, 1986). In other words, lithologic characteristics can be valid criteria in the definition of chronostratigraphic units. From this realization it can be concluded that an integrated lithologic-paleontologic approach is potentially a powerful tool in the delineation of fine-scale chronostratigraphic correlations.

I began research on the Miamitown Shale with such an integrated study of cyclicity in mind (Dattilo, 1996). Having completed a number of fine-scale, lithology-based correlations across the Miamitown-Fairview facies transition, I discovered that a number of thin units already had been recognized within the same stratigraphic interval in the immediate vicinity of Cincinnati. One author (Hyde, 1959) also had traced one of these thin units into the area that later would be designated the type area of the Miamitown Shale (Ford, 1967). Whereas Hyde's (1959) correlations apparently had been intended as chronostratigraphic, and because they were roughly comparable to my own, I began using the old stratigraphic names in my own correlations. This paper presents a documentation of this informal chronostratigraphic nomenclature as seen in five outcrop sections, three of which will be discussed in detail. In no way are the designations of the units intended as formal stratigraphic names; rather, they denote testable hypotheses.

UNIT OVERVIEW

The Miamitown Shale is a thin, mollusk-dominated unit between the Fairview Formation and the Bellevue Member of the Grant Lake Limestone, both of which are considerably more limestone rich and are brachiopod dominated. The interval is intriguing because of this faunal-lithologic contrast and because of the relatively complex geometry of the rapid Miamitown-Fairview facies transition. In the 16 km (10 miles) between Miamitown and Cincinnati (fig. 7-1), the Miamitown Shale thins from about 5 meters (16 ft) to less than 1 meter (3 ft).

STRATIGRAPHIC SEQUENCE AND NOMENCLATURE

A brief history of Cincinnatian fine-scale stratigraphic nomenclature will acquaint the reader with the complexities of the Miamitown interval in Cincinnati. The Miamitown was formally named by Ford in 1967, but a perusal of largely unpublished manuscripts and theses reveals that the gastropod-rich shale has been recognized since the 1930's and perhaps longer. Figure 7-2 compares the finer scale classification by Desjardins, as reported by Forsyth (1946) and published by Hyde (1959), with the more formally published classifications of Nickles (1902) and of Ford (1967). An unpublished U.S. Geological Survey manuscript by Ulrich and Bassler (1914) also contains an interesting reference to a shaly interval between the Fairmount and the Bellevue, the "*Stigmatella irregularis* Zone."

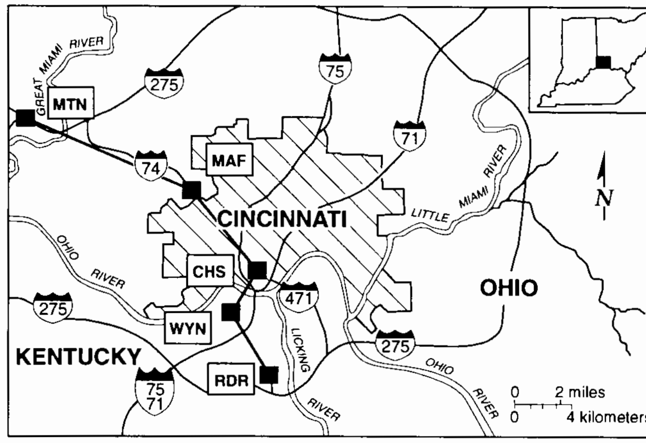

FIGURE 7-1.—Map showing locations of the Miamitown outcrops discussed in this paper and shown on the stratigraphic cross section through these outcrops (fig. 7-4). **CHS** = Rice and Gage Streets/ Christ Hospital (OH-HA-0004), **MAF** = Mt. Airy Forest (OH-HA-0039), **MTN** = Miamitown West (OH-HA-0008), **RDR** = Riedlin Road/ Mason Road (KY-KE-0001), and **WYN** = Wayne Road (KY-KE-0006).

Desjardins (1933, 1934, and 1935) studied the physiography of the Cincinnati area, but also made detailed notes on the bedrock stratigraphy of the area (see Forsyth, 1946). Unfortunately, the only Desjardins stratigraphic column yet located is the generalized one published in Bucher, Caster, and Jones (1939, 1945) (reproduced in part in fig. 7-3). In this column, what is now known as the Miamitown Shale is clearly delineated just above the "*fracta* Zone" in the lowest part of the Bellevue Member. A second shaly horizon, Hyde's "B," is also visible in this rather coarse overview.

Forsyth (1946) described these units in more detail. At the top of the Fairmount Member there are three "*fracta*" or "shingled" zones, each 0.7 meter (2 ft) thick; each successive pair is separated by approximately 1.5 meters (5 ft) of more shaly, even-bedded strata. These zones are characterized by abundant fragmented valves of *Rafinesquina alternata*, *Hebertella occidentalis*, and *Platystrophia*. The uppermost ("first '*fracta*' zone" or "upper shingled") is the most extensive and continuous, whereas the lowest ("third '*fracta*' zone" or "lower shingled") is the least continuous.

Above the shingled zones is a shaly interval 2 meters (5 to 7 ft) thick with a few gastropod-rich limestones called the "gastropod zone" or "gastropod shale" or "zone of abundant gastropods and pelecypods" (Forsyth, 1946). This zone is capped by the 2- to 3-meter (7- to 8-ft) "lower very massive shelly/rubbly" or "lower massive" horizon, which consists mostly of limestone and contrasts markedly with the underlying units. The base of the Bellevue was drawn by

Nickles, 1902	Ulrich and Bassler, 1914	Desjardins *fide* Forsyth, 1946			Hyde, 1959		Ford, 1967	This paper (informal)
Corryville	Corryville	Corryville Member			Undesignated		Unamed	Corryville
Bellevue Limestone	Bellevue Limestone	Bellevue Limestone	upper massive shelly/rubbly horizon	5'-8'	Bellevue Limestone	"A"	Bellevue Limestone	upper massive
			medium light-buff-yellow shaly horizon w/ large full *Rafinesquina alternata*	5'		"B"		*Rafinesquina* shale
	?		lower very massive shelly/rubbly horizon	7'-8'		"C"		lower massive
Fairmount Member	*Stigmatella irregularis* Zone		gastropod zone light-buff-yellow very shaly horizon w/ many gastropods and pelecypods	5'-7'	Fairmount Member	"D"	NW Miamitown Shale	gastropod shale
			first "*fracta*" zone	2'		"E"		upper shingled
	? Fairmount Member	Fairmount Member	undescribed	5'		undesignated	Miamitown Shale / Fairview Formation	middle shale
			second "*fracta*" zone	2'		2nd shingled		middle shingled
			undescribed	5'		undesignated		lower shale
			third "*fracta*" zone	2'		3rd shingled	SE	lower shingled

FIGURE 7-2.—History of stratigraphic nomenclature applied to the Miamitown-Bellevue interval.

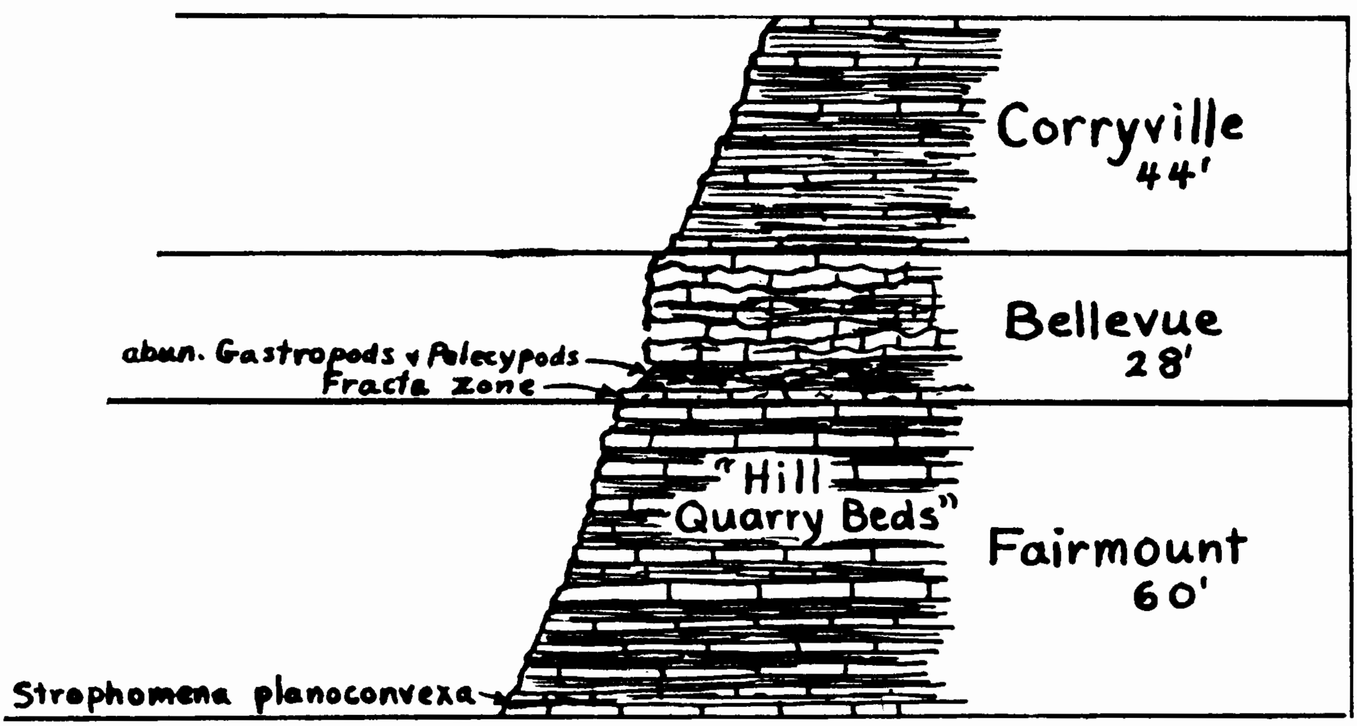

FIGURE 7-3.—Reproduction of part of Desjardins' generalized section showing his Fairmount, Bellevue, and Corryville units and the clear early recognition of the Miamitown Shale or gastropod shale as a marker horizon. From Bucher, Caster, and Jones (1939, 1945).

Desjardins at the base of the first shingled zone, because all of the shingled zones were recognized as being fundamentally Bellevue-like. Nickles (1902), however, placed the base of the Bellevue above all three "*fracta*" or "shingled" zones, at the bottom of the "lower very massive shelly/rubbly horizon," as did Hyde (1959) and Ford (1967).

Above the "lower very massive shelly/rubbly horizon" is a shaly horizon 3 meters (5 ft) thick characterized by large, "full" *Rafinesquina alternata*. Overlying this *Rafinesquina*-bearing shale is an "upper massive shelly/rubbly horizon," the top of which is recognized as the top of the Bellevue.

The stratigraphy of Ford (1967) in this interval differs from that of Nickles (1902) in the important recognition of the Miamitown Shale as a lithofacies that thickens to the northwest.

Instead of numbers or letters, a modified Desjardins nomenclature is used here to denote a set of nearly isochronous units which can be traced between outcrops. These modified, informal designations are listed in the right-hand column of figure 7-2; they are intended as convenient names to be use in discussing stratigraphic relationships. They are in no way intended as formal stratigraphic units.

CORRELATIONS

Figure 7-4 is a correlation chart of three of the outcrops discussed in this paper: Rice and Gage Streets (OH-HA-0004, CHS in figure), Mt. Airy Forest (OH-HA-0039, MAF), and Miamitown West (OH-HA-0008, MTN). Two additional outcrops, Wayne Road (KY-KE-0006, WYN) and Riedlin Road/Mason Road (KY-KE-0001, RDR) also are included. The Riedlin Road/Mason Road site is discussed by Diekmeyer in paper 3 in this volume. These correlations are based primarily on the matching of shale-percentage curves produced by a 1-meter running average of bed-by-bed lithologic data, a method similar to that used by Gray (1972). Details of correlation are corroborated by paleontological data, particularly the stratigraphically limited occurrence of *Heterorthina fairmountensis*, used as a datum in this diagram.

Note that these curves have similar shapes but that the actual percentage of shale at Miamitown West is lower than that at Rice and Gage Streets. In other words, the patterns correlate across facies. The stippled patterns show this clearly; the denser pattern (70 to 100 percent shale) corresponds approximately to the Miamitown Shale facies, which at Miamitown West encompasses the interval between the lower shingled unit and the lower massive unit. At Rice and Gage Streets, the Miamitown facies is limited to the gastropod shale.

The shingled intervals do not display the "shingled facies" everywhere; in some places a given shingled unit may

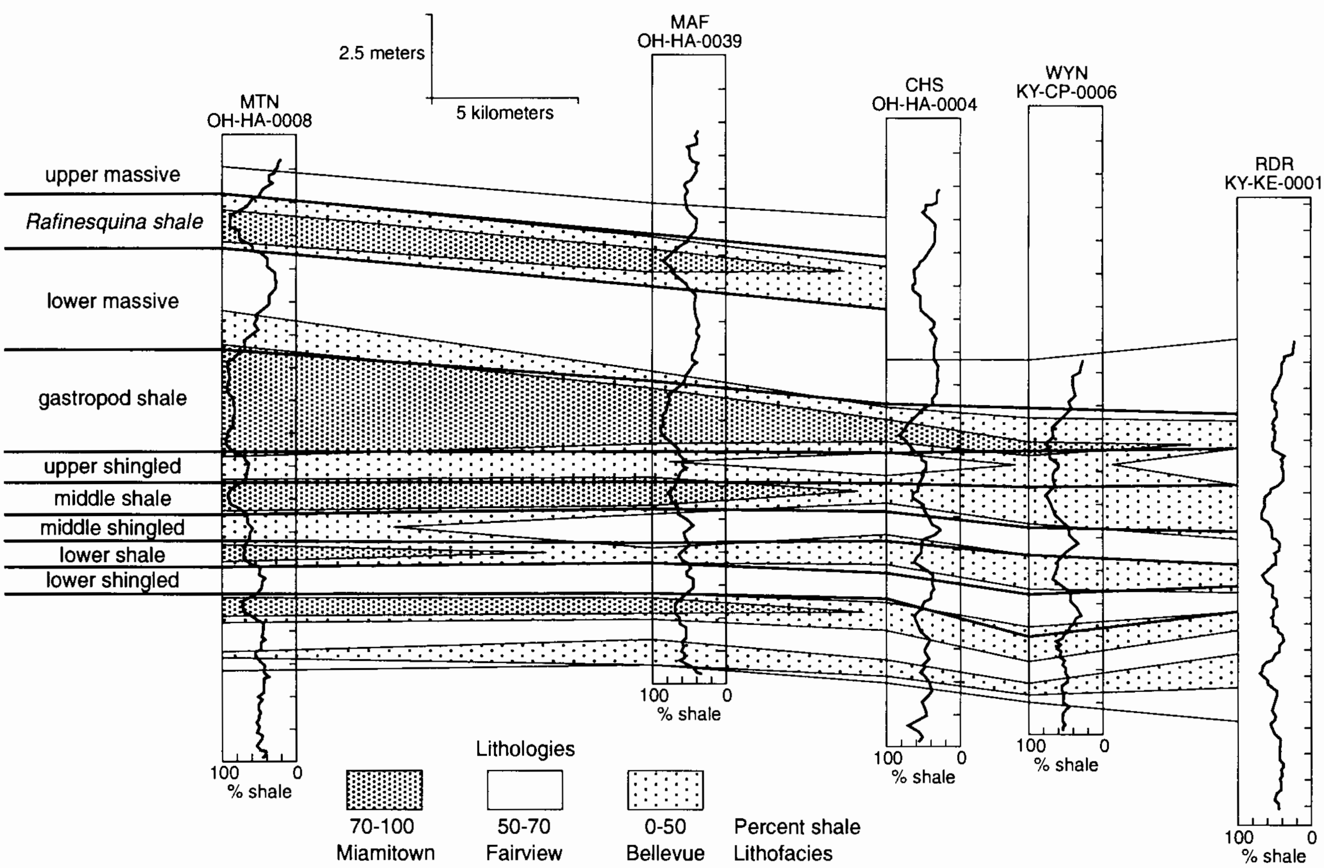

FIGURE 7-4.—Detailed stratigraphic cross section of the Fairview-Miamitown-Bellevue interval from Miamitown West through Cincinnati to Riedlin Road/Mason Road. This diagram shows how shale-percentage curves are used to make high-resolution stratigraphic correlations through a facies transition. The actual position of each section is represented by the left edge of each shale-percentage log. Superimposed on the facies diagram is the informal stratigraphic nomenclature used in this paper. Datum is the stratigraphically restricted *Heterorthina fairmountensis* occurrence. CHS = Rice and Gage Streets/Christ Hospital (OH-HA-0004), MAF = Mt. Airy Forest (OH-HA-0039), MTN = Miamitown West (OH-HA-0008), RDR = Riedlin Road/Mason Road (KY-KE-0001), and WYN = Wayne Road (KY-KE-0006). See figure 7-1 for locations of sections.

contain only tabular limestones without edgewise-stacked *Rafinesquina*, fossiliferous shale, or wavy-bedded limestone that originally made the units noteworthy. This fact does not detract from their usefulness as stratigraphic markers; the upper-shingled-unit "spike" is visible at Miamitown West even though the actual limestones are thin and relatively scattered, and even though no coquina of edgewise *Rafinesquina* is present. The lateral consistency of the shale-percentage pattern probably resulted from rapid and widespread sea-level fluctuations. Each shingled unit, when combined with the underlying shale, may constitute a "cycle" (Tobin, 1982).

DEPOSITIONAL ENVIRONMENT

The stratigraphic position and unusual fauna of the Miamitown Shale make it an interesting study. Molluscan faunas in the Ordovician of the Appalachian Basin have been thought of as indicating relatively shallow water, and the Miamitown Shale occurs just below the Bellevue, which contains clear indicators of shallow-water deposition such as fragmented, abraded shells and robust specimens. On the other hand, the Miamitown is a fine-grained facies that must have been deposited in relatively calm water. Further work with benthic macrofossils may help in interpretation.

A regional stratigraphic cross section (fig. 7-5) illustrates how the Miamitown is a small part of a system of shales from the northwest intertonguing with limestones from the southeast. A simple interpretation of this pattern is that limestone-rich intervals represent shallower water, and shale-rich intervals represent deeper water; the intertonguing resulted from fluctuations in sea level. Notice that the upper part of the Bellevue reaches the farthest to the northwest, indicating that it is the top of a major shoaling-upward cycle. The Miamitown, positioned as it is toward the top of this cycle, is probably not comparable directly to the Kope Formation below. The shaly composition is the product of the rate of sea-level change rather than a reflection of absolute depth; it was probably deposited in shallower water than was most of the Kope.

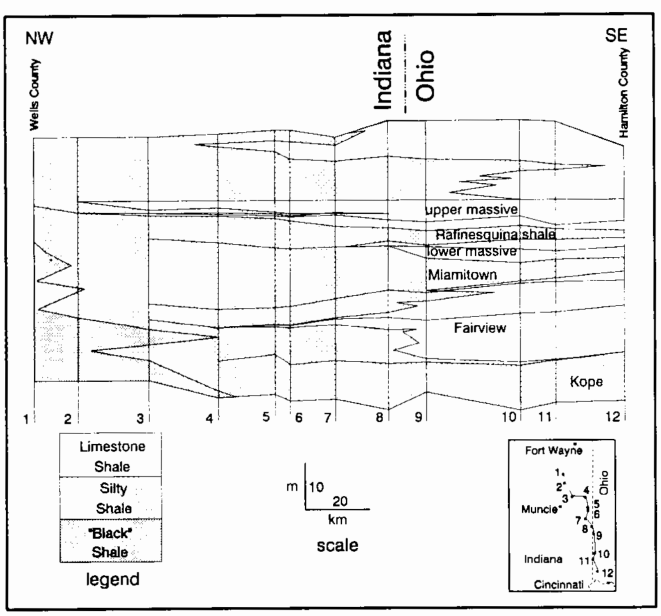

FIGURE 7-5.—Regional stratigraphic cross section of the Kope-Bellevue interval from Wells County, Indiana, to Hamilton County, Ohio. This diagram shows the major facies transitions as indicated by subsurface data.

CINCINNATI OUTCROPS: BELLEVUE HILL, EMMING STREET, AND RICE AND GAGE STREETS

SIGNIFICANCE

Outcrops around downtown Cincinnati have been more accessible to study historically than other outcrops; hence, a number of them are type sections. Three outcrops are of particular interest with respect to the Miamitown interval: (1) Bellevue Hill (OH-HA-0003), (2) Emming Street (OH-HA-0002), and (3) Rice and Gage Streets (OH-HA-0004) (fig. 7-6).

Bellevue Hill is one of the longest standing outcrops from which the Cincinnatian section has been studied. It is the original type section of the Bellevue Limestone (Nickles, 1902), the neotype section of the Fairview Formation (Ford, 1967), and probably formed a basis for Desjardins' generalized stratigraphic section. In addition to this, numerous studies have been made on its fauna and lithologic sequence.

Emming Street, located only a few blocks from Bellevue Hill, is more safely accessible for a close-up look. There are good exposures of the Miamitown/gastropod shale and the Bellevue Limestone, including the upper contact with the Corryville Formation.

Rice and Gage Streets is the neotype section of the Bellevue Limestone (Ford, 1967) and lies very close to the original type section on Bellevue Hill. It exposes the Fairview, Miamitown, and Bellevue units.

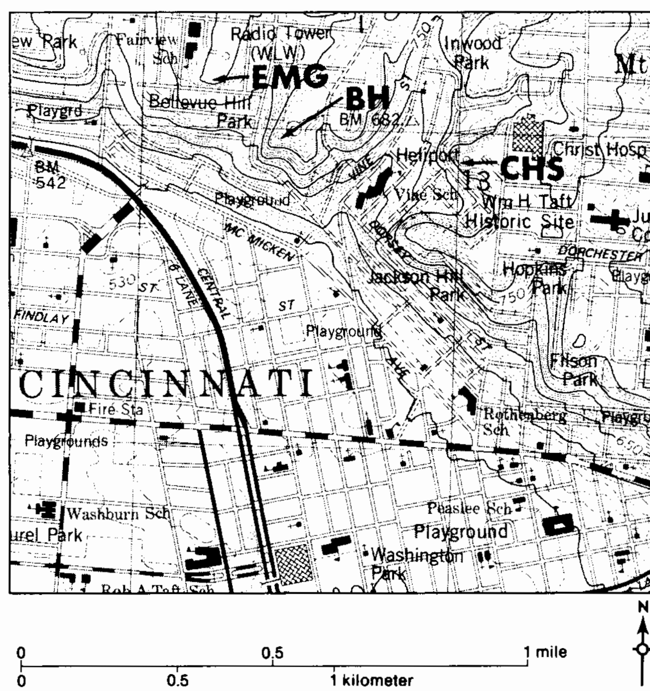

FIGURE 7-6.—Locations of outcrops in Cincinnati proper. Covington, Kentucky–Ohio, 7.5-minute quadrangle. **BH** = Bellevue Hill (OH-HA-0003), **EMG** = Emming Street (OH-HA-0002), and **CHS** = Rice and Gage Streets/Christ Hospital (OH-HA-0004).

LOCATIONS

The Bellevue Hill site (OH-HA-0003) lies just under Bellevue Hill Park to the east of Clifton Avenue, in sec. 13, City of Cincinnati, Hamilton County, Ohio, on the Covington, Kentucky–Ohio, 7.5-minute quadrangle (fig. 7-6). Parking and traffic are problems with all of the Cincinnati outcrops. It probably is unwise to visit Bellevue Hill from Clifton Avenue; fencing has been installed to prevent rock slabs from falling into Clifton Avenue; unfortunately, rocks dislodged by a climbing geologist commonly leap the fence and end up in the street, thereby endangering passing vehicles. If approached from Bellevue Hill Park, the Miamitown/gastropod shale through Corryville can be examined easily.

The Emming Street site (OH-HA-0002) is an old quarry face on the north side of Emming Street, in sec. 19, City of Cincinnati, Hamilton County, Ohio, on the Covington, Kentucky–Ohio, 7.5-minute quadrangle (fig. 7-6). Emming Street, only a few blocks from Bellevue Hill, is much more accessible. At the present time the exposure is limited to the interval between the upper shingled zone and the Bellevue-Corryville contact.

The Rice and Gage Streets site (OH-HA-0004) (fig. 7-7) is at the intersection of Rice and Gage Streets, on the north side of Gage Street, under the Christ Hospital heliport, in sec. 13, City of Cincinnati, Hamilton County, Ohio, on the Covington, Kentucky–Ohio, 7.5-minute quadrangle, 4332909 m N, 714976 m E, UTM zone 16 (fig. 7-6). This locality is the private property of Christ Hospital, but can be viewed easily from the streets themselves. If more intensive study or sampling is required, contact the Public Relations Department of Christ Hospital for permission.

LITHOLOGIC AND FAUNAL SEQUENCE

These Cincinnati sections, all rather close together, differ little from each other or from Desjardins' summary sections. Figure 7-8 illustrates some specific lithologic and faunal occurrences. All three shingled zones display a "coquinoid" facies consisting of shale with fragments of the brachiopods *Rafinesquina alternata*, *Hebertella occidentalis*, *Platystrophia* sp., and bryozoans. The fauna of the intervening shales is sparse, but the middle shale contains a molluscan fauna

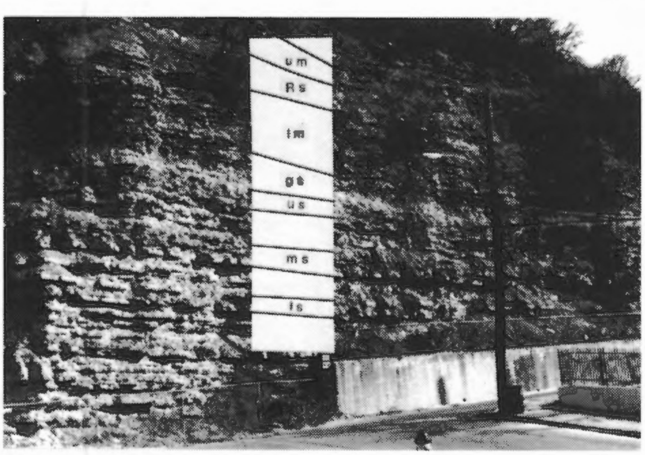

FIGURE 7-7.—Photograph of Rice and Gage Streets locality, showing boundaries of stratigraphic units. ls = lower shingled; ms = middle shingled; us = upper shingled; lm = lower massive; Rs = *Rafinesquina* shale; um = upper massive.

consisting largely of the gastropod *Loxoplocus bowdeni*, the pelecypod *Modiolopsis*, and abundant brachiopods of the genus *Zygospira*. The gastropod shale contains nodular siltstones in which lingulid brachiopods are common. Near the top of this unit is the characteristic gastropod packstone (again, mostly *Loxoplocus bowdeni*).

The lower massive unit is particularly limestone rich; it contains wavy limestone beds 5 to 15 cm (2 to 6 inches) thick interbedded with subequal amounts of highly fossiliferous shale. Fossils are dominated by bryozoans, some colonies of which are "massive" or round and up to 15 cm (6 inches) across. *Platystrophia ponderosa*, other *Platystrophia*, *Hebertella occidentalis*, and *Rafinesquina alternata* also are common. The *Rafinesquina* shale contains large *Rafinesquina* concentrated in one or two beds. The upper massive unit contains a great abundance of large *Rafinesquina alternata* in highly fossiliferous shale with a few wavy-bedded limestones.

MT. AIRY FOREST INTERSTATE CUT

SIGNIFICANCE

This series of road cuts (OH-HA-0039) exposes Kope through Corryville strata. It is one of the largest and most continuous exposures of this interval in the area.

LOCATION

The Mt. Airy Forest site (OH-HA-0039) is a series of large road cuts on either side of I-74 between mile 15.6 and mile 16.8 where it passes through Mt. Airy Forest, sec. 4, Green Township, Hamilton County, Ohio, on the Cincinnati West, Ohio, 7.5-minute quadrangle, 438000 m N, 709000 m E, UTM zone 16 (fig. 7-9). Permission from the Ohio Department of Transportation is required for close examination and sampling of this interstate cut. It is also a steep cut (fig. 7-10), and climbing it may be risky both to the geologist and to motorists.

LITHOLOGIC SEQUENCE

This outcrop contains less limestone than the Cincinnati outcrops (compare figs. 7-8 and 7-11). The shingled units in particular are less well developed, and the intervening strata are very shaly. The fauna of these intervals is not markedly different from the fauna at Rice and Gage Streets, but the gastropod and pelecypod fauna of the gastropod shale is more diverse. Beds from this interval may contain *Modiolopsis*, *Ambonychia*, *Platystrophia*, *Zygospira*, as well as the abundant *Loxoplocus bowdeni*. "Float" specimens of small, well-preserved edrioasteroids probably also originate from this unit. The Miamitown Shale lithofacies extends down through the middle shale unit.

The lower massive unit, still in marked contrast to the underlying intervals, also contains less limestone than it does in Cincinnati. The *Rafinesquina* shale contains pelecypods at this locality. The upper massive unit probably is the source of large semi-articulated edrioasteroids that have been found in float material.

MIAMITOWN WEST

SIGNIFICANCE

This series of road cuts on the interchange between I-74

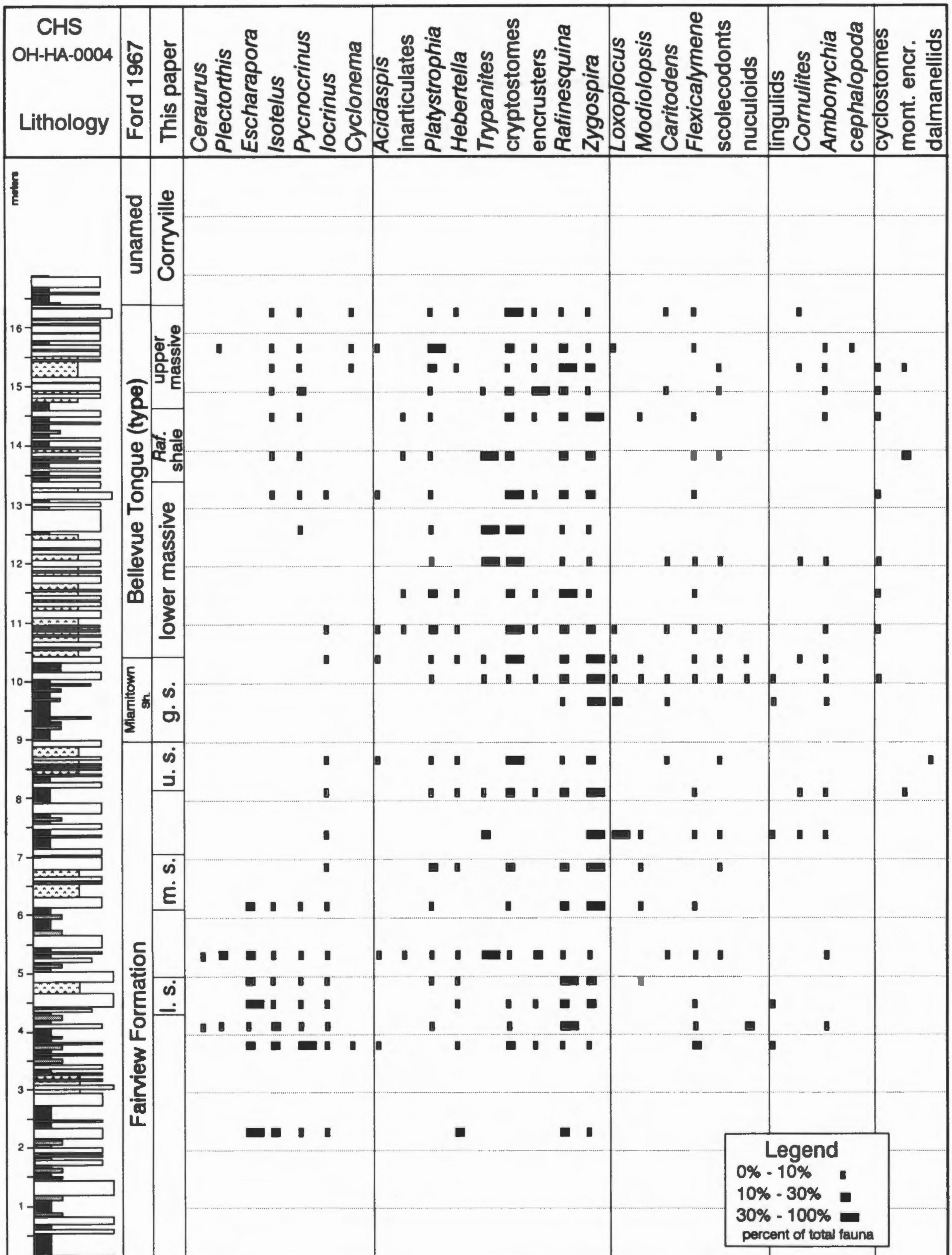

FIGURE 7-8.—Measured columnar section of the Rice and Gage Streets site (1:100), showing lithologies (see fig. 9-5 for patterns), Ford (1967) nomenclature, informal detailed stratigraphic nomenclature, and relative abundances of selected fossils, ordered according to occurrence as shown by cluster analysis. l.s. = lower shingled; m.s. = middle shingled; u.s. = upper shingled; g.s. = gastropod shale; mont. encr. = monticulated encrusting bryozoans.

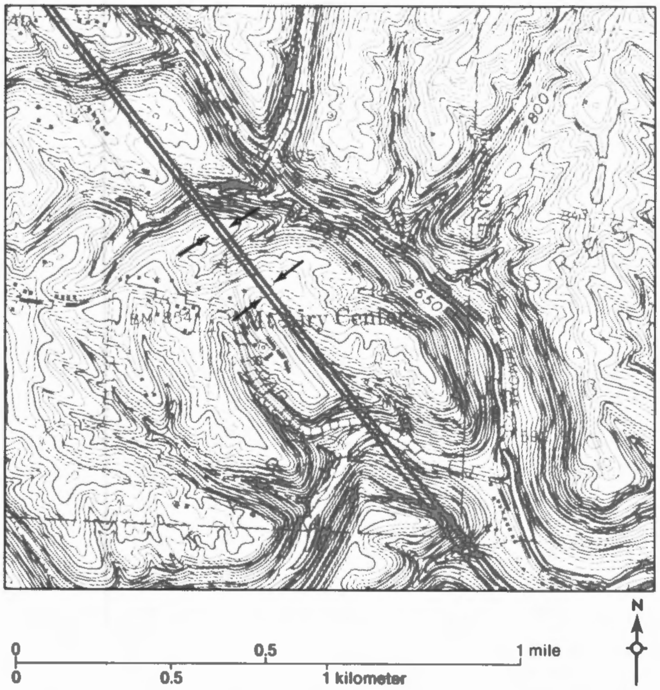

FIGURE 7-9.—Locations of Mt. Airy Forest road cuts (OH-HA-0039). Cincinnati West, Ohio, 7.5-minute quadrangle.

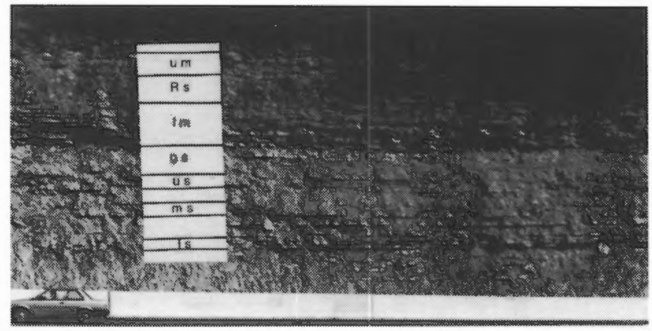

FIGURE 7-10.—Photograph of Mt. Airy Forest road cut, showing stratigraphic contacts. ls = lower shingled; ms = middle shingled; us = upper shingled; lm = lower massive; Rs = *Rafinesquina* shale; and um = upper massive.

and I-275 west of Miamitown provides an expanded exposure of Ford's (1967) original type section for the Miamitown Shale, the "Highway cuts west of Miamitown." Because I-275 had not been constructed at the time, Ford's observations were limited to the cuts around the original I-74 (still well exposed). Now the northernmost cut, on the interchange ramp from I-74 west to I-275 south, provides an exposure of the upper massive and *Rafinesquina* shale units (fig. 7-12) not visible when Ford did his original work. Similarly, the southernmost cut exposes several additional meters of strata just below the original type section.

LOCATION

The Miamitown West site (OH-HA-0008) is located at the interchange between I-74 and I-275 northwest of Miamitown, Hamilton County, Ohio. The locality consists of six road cuts surrounding the various roadways of the interchange, in sec. 35, Whitewater Township, Hamilton County, Ohio, on the Addyston, Ohio–Kentucky, 7.5-minute quadrangle, 4343499 m N, 695446 m E, UTM zone 16 (fig. 7-13). As with all interstate highway cuts, permission from the Ohio Department of Transportation is required. Otherwise, all of the road cuts are generally accessible and relatively safe to the careful driver.

LITHOLOGIC AND FAUNAL SEQUENCE

A quick glance at figure 7-14 reveals the remarkable amount of shale in the shingled intervals. The upper shingled unit contains a thick grainstone and some fossiliferous shale, and the middle and lower shingled units are barely distinguishable. The Miamitown lithofacies extends down to the top of the middle shingled unit. Faunally, the gastropod shale is still distinctive and contains the same gastropod-*Zygospira*-bivalve assemblage, but gastropods and pelecypods can be found throughout the Miamitown lithofacies. The upper shingled interval contains a few unusual fossils; in or around this interval are localized deposits of small *Rafinesquina* (2-3 cm in length) and small edrioasteroids.

The lower massive unit here contains much less limestone than at the previous outcrops, and the fauna is different; *Rafinesquina*, *Zygospira*, and bryozoans (not large colonies) dominate. The *Rafinesquina* shale is relatively unfossiliferous; it contains a few *Rafinesquina* and some mollusk-rich siltstones. The upper massive unit, again less limestone rich than at Cincinnati, is dominated by *Rafinesquina* and contains large, poorly preserved edrioasteroids.

ACKNOWLEDGMENTS

This research was supported in part by the following grants: Cincinnati Museum of Natural History Research Grant 1989, Geological Society of America research grants 4402-90 and 4666-91, Paleontological Society/Margaret C. Wray Trust grant-in-assistance 1991, and Sigma Xi grant in aid of research 1991.

ADDITIONAL LOCALITIES FOR THE MIAMITOWN SHALE

For details on locations, see Appendix A at the end of this volume.

Ashtree Drive and Hamilton Avenue (OH-HA-0041). Fairview through lower Bellevue exposed. Climbing gear required.

Congress Run (OH-HA-0016). Stream cuts along Congress Run and tributary to Congress Run extending 0.5 mile (0.8 km) north from intersection with Galbraith Road east of Winton Road. Section measured in detail by Ford and Osborne in 1963, Ohio Division of Geological Survey measured section no. 15373.

Crosby Road (OH-HA-0017). Section measured in detail by Ford in 1964, Ohio Division of Geological Survey measured section no. 15379.

Delhi Pike (OH-HA-0040). Contains Fairview and Miamitown strata. Section measured in detail by Swinford and Vormelker in 1985, Ohio Division of Geological Survey measured section no. 16879.

Lawrenceburg (KY-BE-0003). Road cuts on either side of I-275 in Boone County, Kentucky, 0.4 mile (0.7 km) south of the Ohio River across from Lawrenceburg, Indiana.

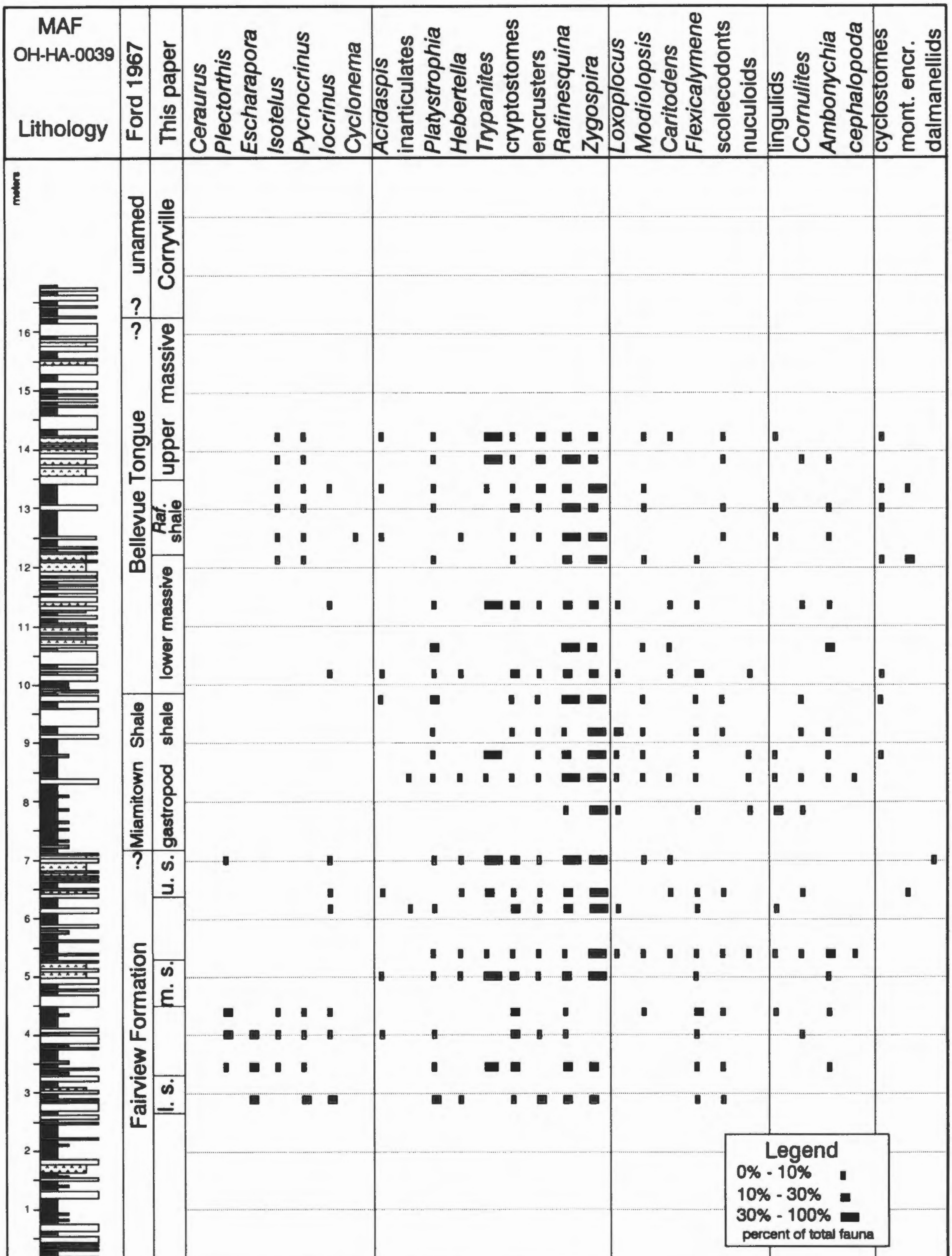

FIGURE 7-11.—Measured columnar section of Mt. Airy Forest strata (1:100), showing lithologies (see fig. 9-5 for patterns), Ford (1967) nomenclature, informal detailed stratigraphic nomenclature, and relative abundances of selected fossils, ordered according to occurrence as shown by cluster analysis. l.s. = lower shingled; m.s. = middle shingled; u.s. = upper shingled; g.s. = gastropod shale; mont. encr. = monticulated encrusting bryozoans.

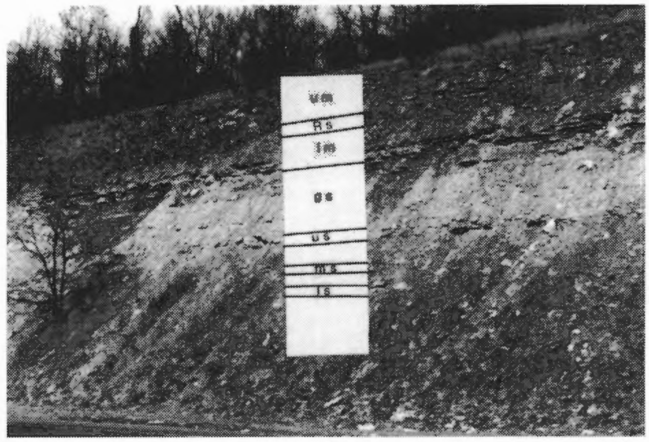

FIGURE 7-12.—Photograph of Miamitown West road cut, showing stratigraphic contacts. ls = lower shingled; ms = middle shingled; us = upper shingled; lm = lower massive; Rs = *Rafinesquina* shale; and um = upper massive.

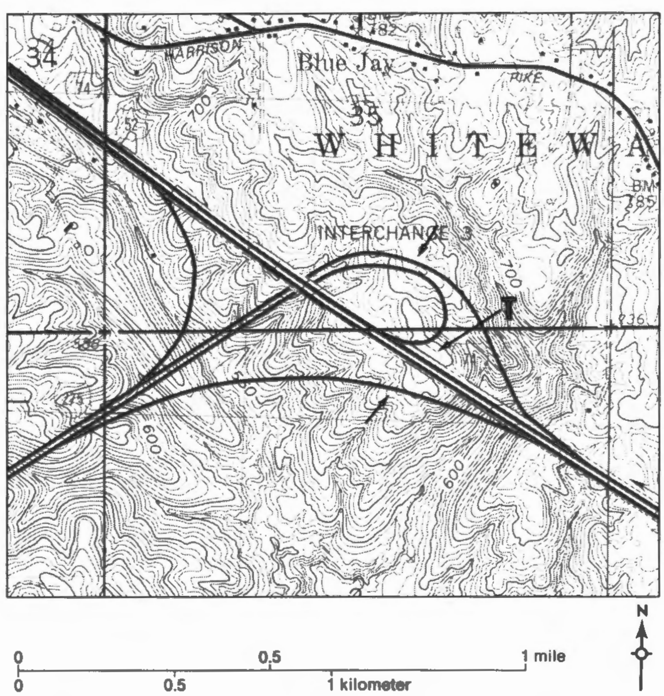

FIGURE 7-13.—Location of Miamitown West road cuts (OH-HA-0008). **T** = approximate location of the original type section of the Miamitown Shale. Addyston, Ohio–Kentucky, 7.5-minute quadrangle).

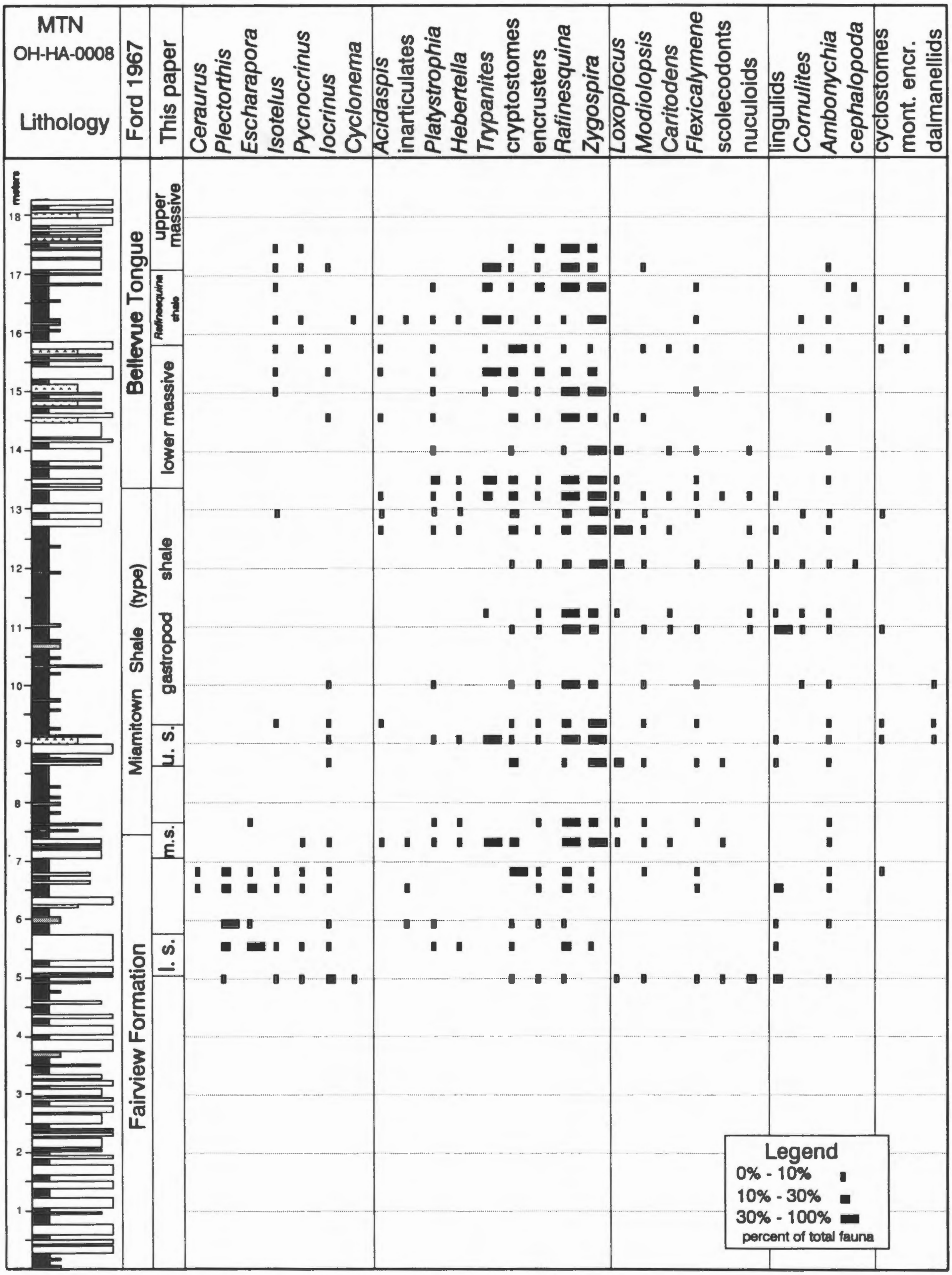

FIGURE 7-14.—Measured columnar section of strata at the Miamitown West locality (1:100), showing lithologies (see fig. 9-5 for patterns), Ford (1967) nomenclature, informal detailed stratigraphic nomenclature, and relative abundances of selected fossils, ordered according to occurrence as shown by cluster analysis. l.s. = lower shingled; m.s. = middle shingled; u.s. = upper shingled; g.s. = gastropod shale; mont. encr. = monticulated encrusting bryozoans.

Muddy Creek (OH-HA-0020). Upper Fairview, Miamitown, and Bellevue Formations are exposed in a series of stream cuts along Muddy Creek west of Beech Grove Drive. Sections measured in detail by Ford in 1963, Ohio Division of Geological Survey measured section nos. 15376, 15458, and 15459.

Riedlin Road/Mason Road (KY-KE-0001). See Diekmeyer (paper 3 in this volume).

Sheits Road (OH-HA-0023). Section measured in detail by Ford in 1964, Ohio Division of Geological Survey measured section no. 15380, and by Swinford and Vormelker in 1985, Ohio Division of Geological Survey measured section no. 16872.

Wayne Road (Devou Park) (KY-KE-0006). Exposures of upper Fairview, Miamitown, and lower Bellevue. Included on figure 7-4 cross section.

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Address of author: Benjamin F. Dattilo, Geoscience Department, Weber State University, 2507 University Circle, Ogden, UT 84408-2507 (formerly at the Department of Geology, University of Cincinnati).

8. THE BROOKVILLE DAM SPILLWAY—MIAMITOWN THROUGH WAYNESVILLE FORMATIONS (UPPER ORDOVICIAN, SOUTHEASTERN INDIANA)

by
Helen B. Hay and Roger J. Cuffey

SIGNIFICANCE

The Brookville Dam section (fig. 8-1), combined with the Bon Well Hill, Garr Hill, and South Gate Hill sections (see papers 10, 11, and 12 in this volume), form the Brookville composite section (fig. 8-2). Collectively they expose almost the entire Maysvillian and Richmondian succession in southeastern Indiana. "The importance of these sections lies not only in the stratigraphic thickness exposed and the high quality of the exposures, but also in their geographic location along the northwestern side of the Cincinnati Arch. The lower half of the section correlates with strata exposed in Ohio from Cincinnati northward to Middletown, Ohio, and the upper half correlates with outcrops around the margin of the arch. Therefore, the Brookville composite section is a key section in regional stratigraphic work" (Hay, 1977, p. I-6).

LOCATION

The Brookville Dam spillway (IN-FR-0002) is located at the western end of that dam, where the water flows over the dam and down to the river level below, roughly a mile north of Brookville, Franklin County, Indiana (fig. 8-1). From the junction of U.S. Route 52 and Indiana Route 101 near the northern edge of Brookville, proceed 1.3 miles (2.1 km) northeast on Indiana Route 101, turn sharply northwest for 0.2 mile (0.3 km), and then drive 0.6 mile (1.0 km) west across the top of the dam. The road ends in a turn-around circle overlooking the spillway below and to the southwest. Alternatively, there is also convenient parking along Indiana Route 101 just west of the bridge crossing the Whitewater River, below the dam, only 0.6 mile (1.0 km) northeast of that junction. The spillway section lies in SW1/4SE1/4SE1/4 sec. 17 and NW1/4NE1/4NE1/4 sec. 20, T. 9 N., R. 2 W., Brookville, Indiana, 7.5-minute quadrangle, at 39°26'13"N latitude, 85°00'19"W longitude (4366972 m N, 671679 m E, UTM zone 16). Elevation of the base of the spillway is 623 ft (189.9 meters), at river level in the valley bottom out in front of the dam. From the traffic circle at the west end of the dam-top road, the spillway and the measured section are down to the left (southwest).

Across the spillway to the right (northwest) is a highwall exposing 60 meters (200 ft) of Ordovician bedrock, which correlates with the strata exposed at Garr Hill and the upper part of Bon Well Hill (see papers 10 and 11 in this volume). The height and steepness of the highwall make access very difficult, and, indeed, access is not normally permitted.

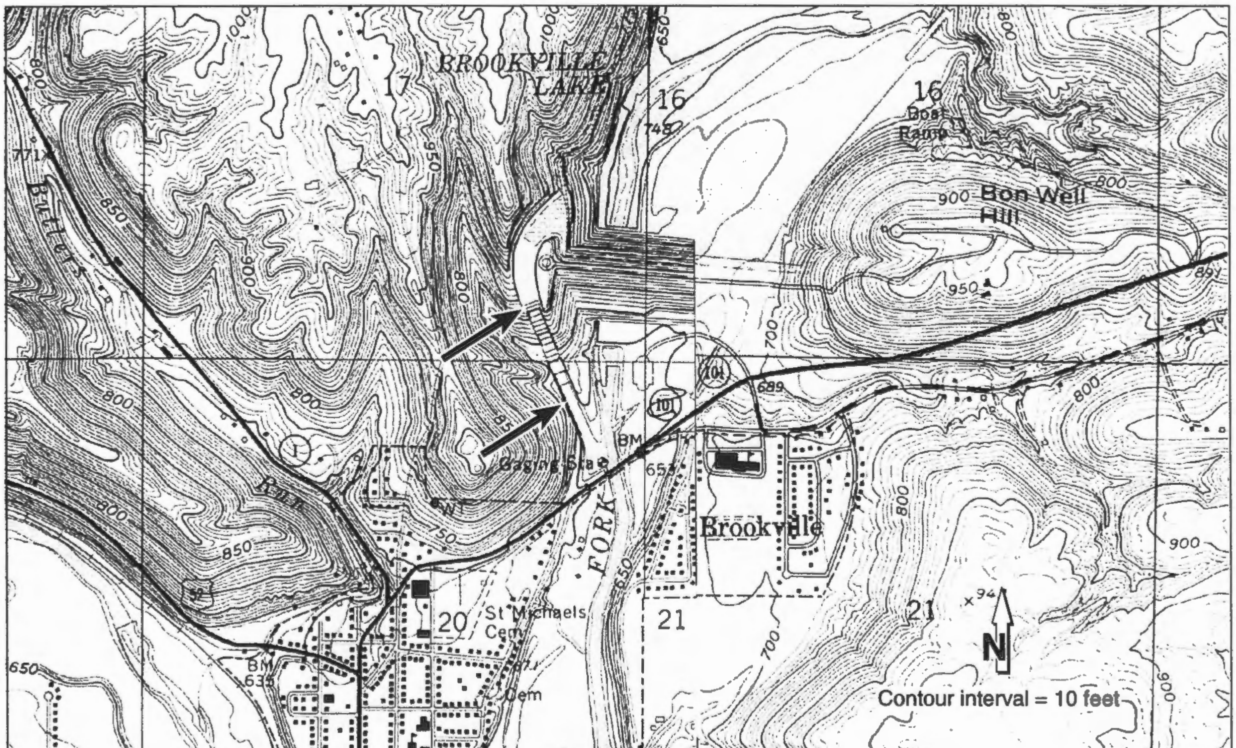

FIGURE 8-1.—Location of the Brookville Dam spillway (between the two arrows), on the Brookville (left) and Whitcomb (right), Indiana, 7.5-minute topographic quadrangles (note difficulties in matching contours and roads along their common border).

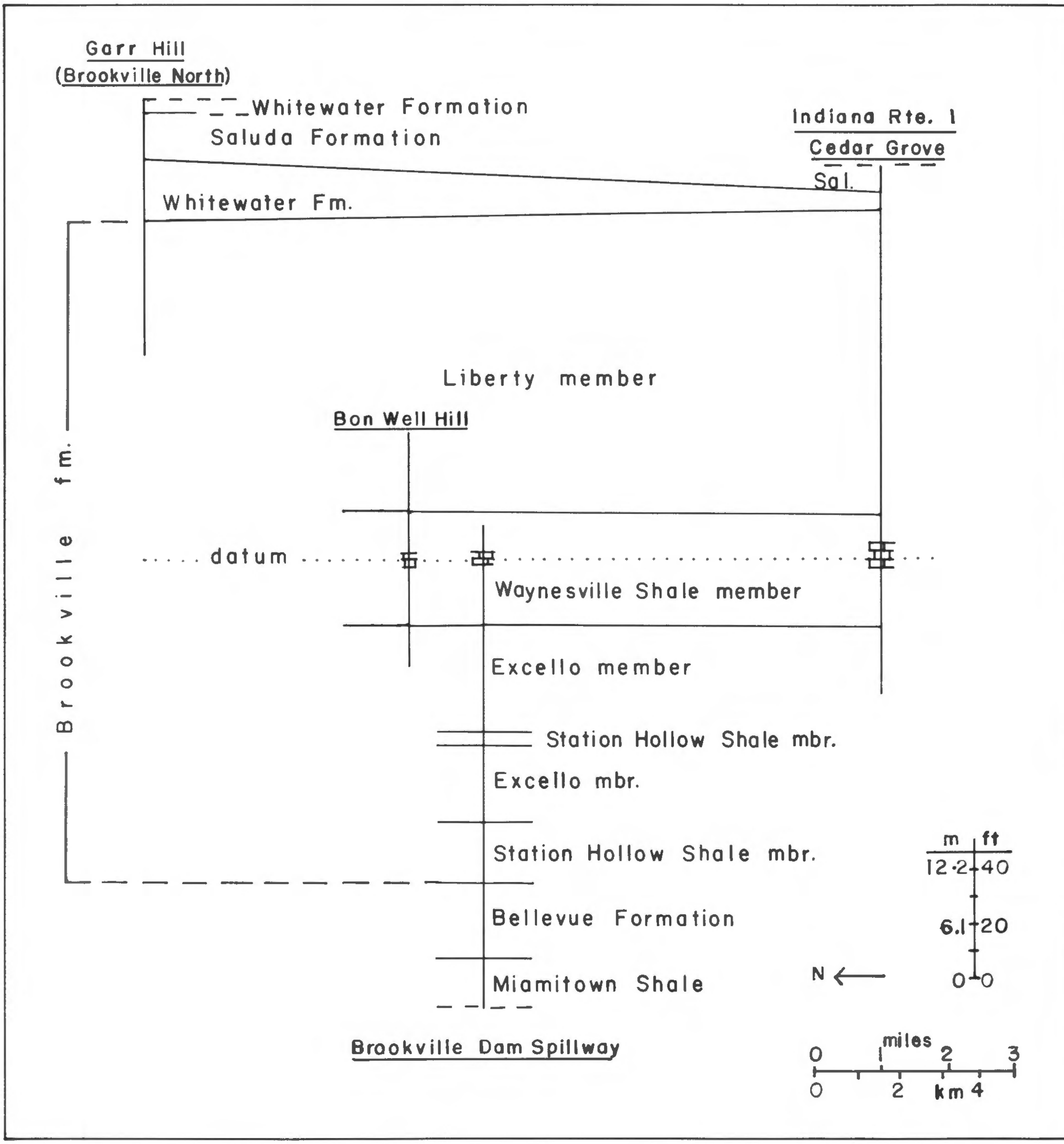

FIGURE 8-2.—Correlation of the four localities that collectively make up the Brookville composite section: Brookville Dam spillway (IN-FR-0002), Bon Well Hill (IN-FR-0001), Garr Hill/Brookville North (IN-FR-0003), and South Gate Hill/Indiana Route 1, labeled as Cedar Grove (IN-FR-0005).

For information about examining these exposures, contact the U.S. Army Corps of Engineers, Brookville Lake Office, P.O. Box 230, Brookville, Indiana, 47012.

STRATIGRAPHY

The stratigraphic section visible in the spillway is summarized in figure 8-3, which is updated from a preliminary version published some years ago (Hay, 1977, 1981). The lithofacies (fig. 8-4) and the stratigraphic nomenclature used here are discussed more fully in paper 17 of this volume (also see Hay, 1981, and Hay and others, 1981).

ACKNOWLEDGMENTS

Susan Hovorka, Timothy Knisely, and John Webb helped de-

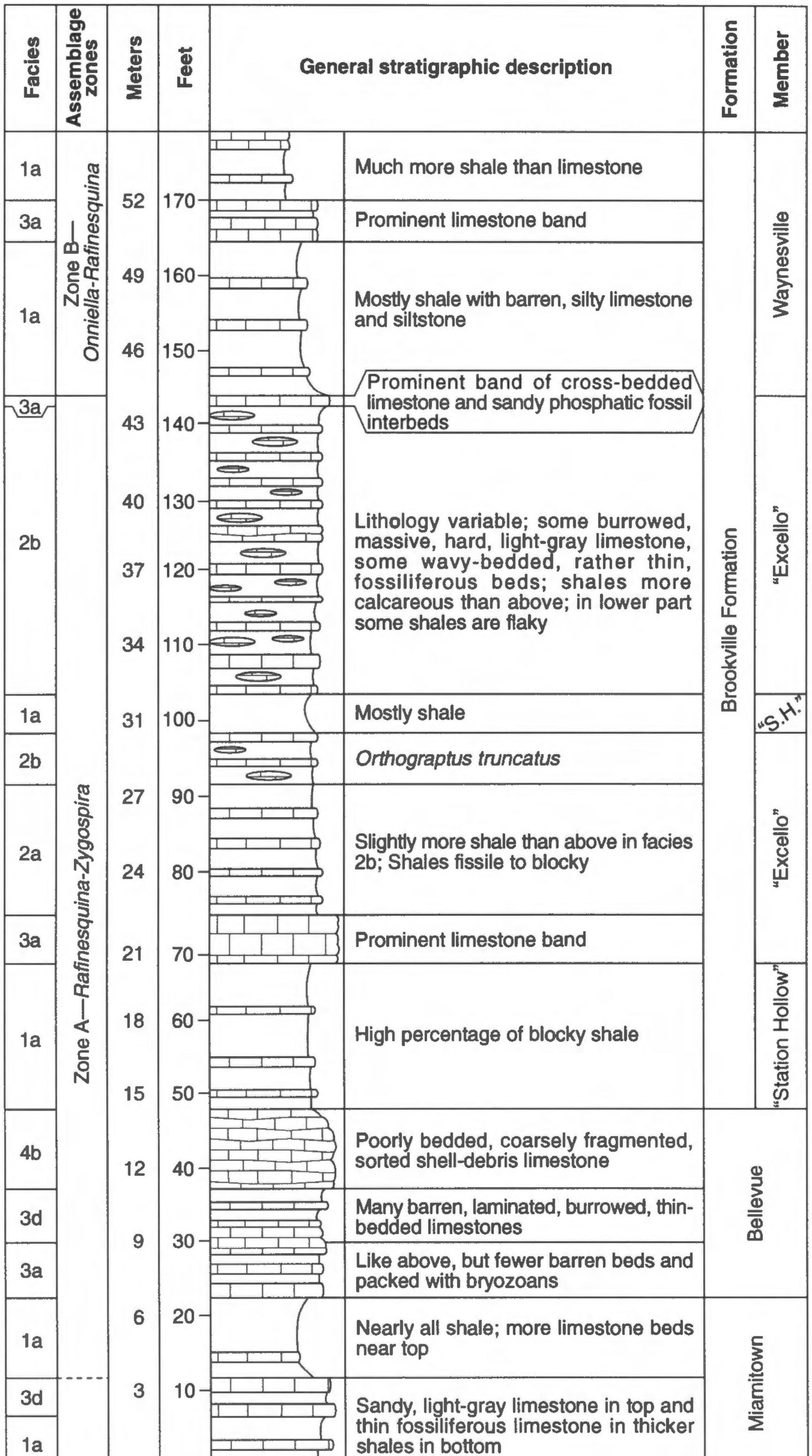

FIGURE 8-3.—Stratigraphic section exposed in the Brookville Dam spillway (modified from Hay, 1977, p. I-27, fig. I-11, and Hay, 1981, p. 151).

Principal diagnostic characteristics of lithofacies		
Group 1 >70% shale	1a	Well-bedded, mostly thin limestones and medium to thick, fissile to blocky shales. Includes massive units of 100% shale. Low-diversity fauna.
	1b	Rubbly, shaly, nodular limestones; medium to thick shales with limy stringers and layers of fossils in shale matrix. May have some well-bedded limestones as in 1a. Low-diversity fauna. Most easily seen in cores.
Group 2 55-70% shale	2a	Like 1a except has high diversity of fauna. Intermediate in shale percentage between 1a and 3a.
	2b	Well-bedded limestones, rubbly nodular limestones, and limy shales. Allochems tend to be more finely broken than 2a. High-diversity fauna. Intermediate between 3a and 3c.
Group 3 <55% shale	3a	Well-bedded, thin to medium limestones and thin to medium, fissile to blocky shales. High-diversity fauna.
	3b	Well-bedded, thin to medium limestones with or without rubbly or nodular shales. High-diversity fauna. Intermediate between 3a and 3c.
	3c	Thin-bedded, rubbly weathering, argillaceous limestones, very thin limy shales. High-diversity fauna.
	3d	Limestones and shales as in 3a except >20% of limestones are fine-grained laminated burrowed, barren of large fossils; trails on tops. Grade to siltstones.
Group 4 Miscellaneous	4a	High-angle cross-bedded calcarenites, bimodal dip. Little or no shale.
	4b	Granule-size fossils in thick to massive beds; little or no shale. May be like 4a if seen in similar outcrops.
	4c	Massive *Loxoplocus* limestone bed. Marble Hill Bed.
	4d	Bioturbated light-gray limestone with low-diversity fauna of ostracodes, algae, snails, and *Tetradium*. Related to Saluda facies complex.

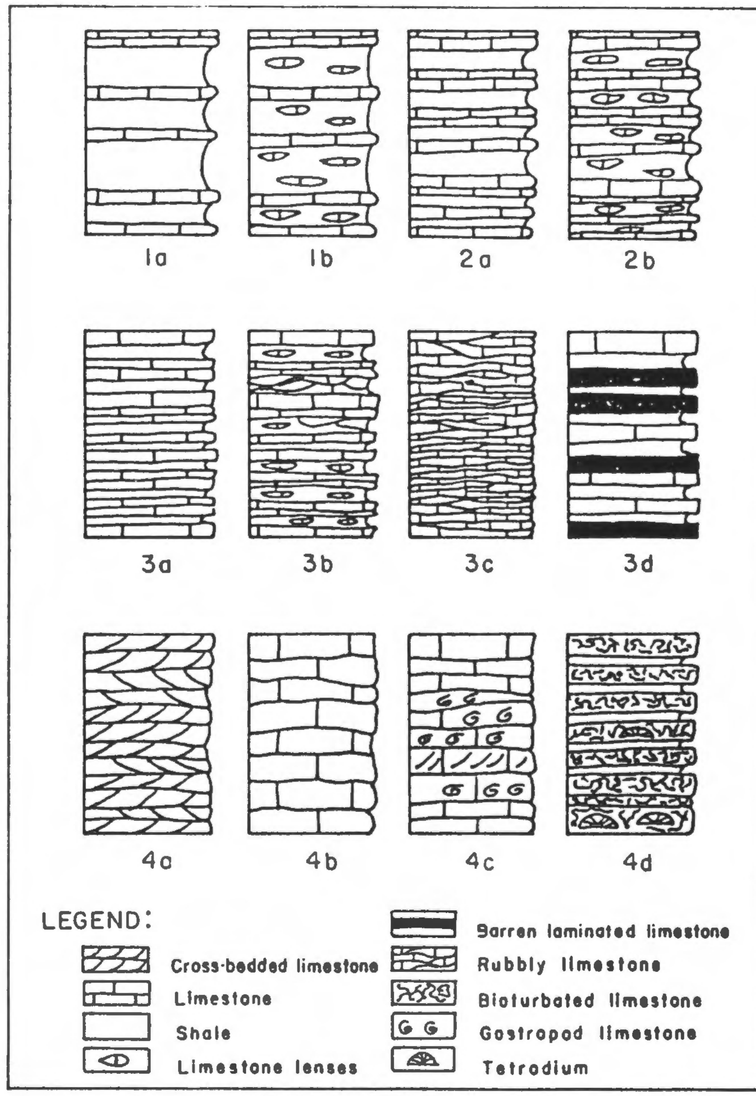

FIGURE 8-4.—Lithofacies characteristics (see Hay, paper 17 in this volume).

scribe the spillway section initially. At the time they were students in Independent Study in Geology at Earlham College.

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Addresses of authors: Helen B. Hay, deceased, formerly Geology Department, Earlham College, Richmond, IN 47374; and Roger J. Cuffey, Department of Geosciences (Deike Bldg.), Pennsylvania State University, University Park, PA 16802.

9. THE CORRYVILLE MEMBER OF THE GRANT LAKE FORMATION (UPPER ORDOVICIAN, SOUTHWESTERN OHIO)

by
Lawrence I. Goldman

INTRODUCTION

The Corryville Member of the Grant Lake Formation in southwestern Ohio is a thick-bedded, shale-rich (63 percent) facies that contains the most diverse open-marine fauna in the Cincinnatian Series, including rare, articulated macroinvertebrate taxa. The unit is composed of planar-bedded, fossiliferous limestones and thick, platy- to flaggy-parted, sparsely fossiliferous shales. The Corryville Member has been interpreted as a transgressive facies at the base of a third-order shoaling-upward cycle (Tobin, 1982). Deposition was storm dominated and took place in a shallow epeiric sea just offshelf of a broad, gently sloping, west-facing carbonate ramp. The Corryville Member grades south and southwest from the Grant Lake Formation into the stratigraphically equivalent Grant Lake Limestone in Kentucky, a carbonate-rich unit that has been interpreted as having been deposited in a more proximal ramp setting. A specific type section for the Corryville does not exist, so this paper will discuss both the original "type area" and the proposed type section (Schumacher and others, 1991) (fig. 9-1).

DESCRIPTION

HISTORY OF STRATIGRAPHIC NOMENCLATURE

The Corryville Member initially was recognized by Nickles (1902) from exposures in the Cincinnati area and was named for the community of Corryville, a northern Cincinnati neighborhood within which many of the unit exposures were situated. Nickles defined the unit primarily by the presence and abundance of the characteristic bryozoan *Chiloporella nicholsoni* (fig. 9-7.1) and by the absence of the bryozoan *Monticulipora molesta*, which delineated the underlying Bellevue Beds. Nickles described the Corryville Beds of his Lorraine Group as those in which "the limestones are thinner and less frequent than in the quarry beds and the shales are more yellowish. Blue shale also occurs." (Nickles, 1902, p. 83). The "quarry beds" are the underlying Fairview and Bellevue units. Nickles did not designate a type section for his Corryville Beds. In 1906, Bassler incorporated the Bellevue, Corryville, and the overlying Mt. Auburn Beds as members of the proposed McMillan Formation. Despite the fact that Bassler never published a complete description of the McMillan type section or of its unit boundaries, his McMillan Formation became accepted and uncontested in regional nomenclature for the next half century.

The 1960's and 1970's were a period of reawakened interest in the Cincinnatian Series, marked by a general dissatisfaction with the established stratigraphy and an accompanying desire to redefine the entire Cincinnatian Series along purely lithological criteria. The original nomenclature was universally rejected for its biostratigraphic underpinnings as well as its inability to account for the gra-

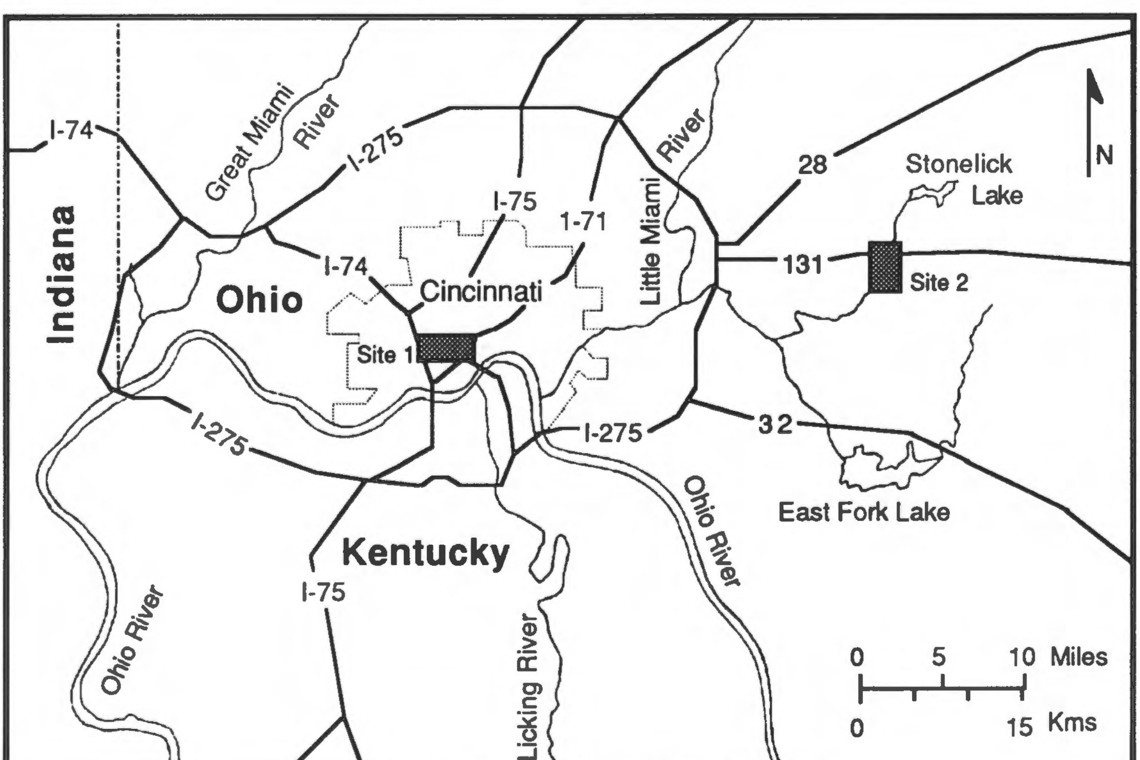


FIGURE 9-1.—Index map showing the locations of site 1, McMillan Street (OH-HA-0027), and site 2, Stonelick Creek (OH-CT-0004).

dational changes from limestone-dominated facies in northern Kentucky to the equivalent shale-dominated strata of southeastern Indiana. As a result, the name Corryville was abandoned, and its facies was incorporated into larger, undifferentiated lithostratigraphic formations, including the Grant Lake Limestone of Kentucky (Peck, 1966), the "unnamed beds" of Ohio (Ford, 1967), and the Dillsboro Formation (Brown and Lineback, 1966) and the "Brookville formation" (Hay, 1981; Hay and others, 1981), both of Indiana. This proliferation of names and boundaries was useful for the description of local rock units, but contributed little to an overall understanding of regional facies relationships. Because none of these studies directly addressed the stratigraphy in the type area, the original nomenclature continued to be used by those persons working within the Cincinnati area.

Research from the 1980's to the present has concentrated on the interpretation of the large-scale depositional dynamics of the Cincinnatian Series and on the regional paleoenvironmental implications of small-scale, intraformational depositional cycles (Tobin, 1982; Jennette, 1986; Diekmeyer, 1990). Tobin (1982) completed the first modern detailed description of the Corryville throughout the southwestern Ohio, southeastern Indiana, and northern Kentucky area. He recognized the Corryville as a mappable unit representative of a distinct deeper water paleoenvironment, and he abandoned the McMillan and reinstated the Corryville as a formation. Tobin (1982, 1986) maintained that, although the original Nickles (1902) descriptions were outdated and lacking in detail, they did represent a valid biostratigraphic and lithostratigraphic identity and so had priority as rock-stratigraphic units.

Schumacher and others (1991) completed a regional documentation of the lithostratigraphic variations within the Bellevue, Corryville, and Mt. Auburn sequence. Through a combination of bedrock mapping, shale-percentage logs, geophysical logs, and mean percentage of shale, Schumacher and others recognized the continuity of these three units within the southwestern Ohio area, but disputed Tobin's (1982, 1986) nomenclature, primarily because the individual units could not be mapped easily at a map scale of 1:62,500 or smaller. In accordance with the guidelines set forth by the 1983 North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983), Schumacher and others reduced the Corryville to a member within the proposed Grant Lake Formation of Ohio, a modification of the stratigraphically equivalent, though lithologically disparate, Grant Lake Limestone. The nomenclature of Schumacher and others (1991) has been adopted for this paper.

LITHOLOGY

The Corryville, the middle member of the Grant Lake Formation, is composed of terrigenous shales and interbedded fossiliferous limestones and calcareous siltstones. Bedding contacts are primarily planar to lenticular, although there are minor amounts of irregular- to wavy-bedded limestones within the lower half of the unit. In southwestern Ohio, the Corryville Member averages 63 percent shale and 37 percent limestone. Mean shale percentages decrease to the south and southeast (<40 percent) and increase to the north and northwest (>70 percent) (Tobin, 1982; Schumacher and others, 1991). The Corryville attains a maximum thickness of more than 21 meters (68.9 ft) in central Warren County, Ohio, and from there thins west, east, southeast, and south. At Maysville, Kentucky, where it is the middle member of the Grant Lake Limestone (Schumacher and others, 1991), its thickness is less than 6 meters (19.7 ft). The Grant Lake Limestone consists of predominantly irregular-bedded limestone (68 percent) and interbedded calcareous, fossiliferous shale (32 percent). Small, accessible stream exposures and road cuts of the Corryville Member of the Grant Lake Formation/Grant Lake Limestone are spread throughout southwestern Ohio, southeastern Indiana, and northern Kentucky (see locality list at the end of this paper and the locality appendix to the volume).

The following description of the Corryville is based mainly on exposures at the Stonelick Creek locality (OH-CT-0004). Carbonate rocks are here classified by texture according to Dunham (1962), as modified by Tobin (1982). Matrix-rich limestones, here referred to as "micstones" (the equivalent of Dunham's "mudstone"), are rare and account for less than 1 percent of all Corryville limestones. The most abundant limestone types are fossiliferous packstones and wackestones. These are poorly sorted, planar, mostly continuous, and in places exhibit upward fining of matrix and fossil content. Grainstones may be coarse, fine, or poorly washed (containing 6-15 percent mud matrix) and are generally more abundant within the lower half of the Corryville section. These limestones are poorly to well sorted, exhibit a moderate to high degree of fossil breakage, and rarely show evidence of bioturbation. Bed contacts are planar, but may be irregular or wavy. Both packstones and grainstones contain internal and external geopetal structures, and mud entrapment by shells is common. Mud clasts and intraclasts are rare. Most of the limestone beds are capped by a distinct, yellowish-gray siltstone, which is sparsely fossiliferous but which may contain trace fossils or articulated brachiopods and pelecypod molds. Bedding surfaces may contain symmetric and asymmetric ripples and current-oriented fossil material, including cephalopods, brachiopods, ramose bryozoans, and crinoids.

Calcisiltites and calcareous siltstones are abundant throughout the Corryville interval and are quite similar in their general appearance. Calcisiltites are defined as very well sorted grainstones with a mean grain size of >0.5 mm and tiny subhorizontally oriented fossil detritus (Tobin, 1982). Siltstones are calcareous and slightly dolomitic and contain small amounts of terrigenous quartz. Both calcisiltite and siltstone strata are thin, generally 1-4 cm (0.4-1.6 inches), but may achieve a thickness of 15 cm (6 inches). Planar lamination, hummocky cross-stratification, and graded bedding are common to both lithotypes. Basal bedding surfaces commonly are erosive and display groove marks, tool marks, flute marks, prod marks, gutter casts, and a lag of small, broken fossils. Fossil material in these beds is sparse, but articulated brachiopods and crinoid stalks of 12 cm (5 inches) or more in length have been found on bedding surfaces. Bioturbation and escape structures are common to both lithotypes, but most traces are restricted to the tops of beds (<2 cm depth) and represent less than 20 to 30 percent reworking of the bed area.

The term "shale" is herein used to describe any predominantly clay-rich bed. In general, Corryville shales are silty, calcareous, and sparsely fossiliferous and display platy to flaggy parting. They are gray to blue when fresh and weather to a yellow-gray color. The average Corryville shale is a dolomitic mudstone with a silt/clay ratio of 1.05 and a mean grain size of 28 micrometers (Tobin, 1982). Average shale thickness is 7 cm (2.8 inches), with a range of 1 to 34 cm (0.4 to 13.4 inches). Evidence of bioturbation is very rare. A few fossiliferous, fissile-parted beds do exist, but in most instances where fossils are present, they are restricted to distinct horizontal layers within an otherwise sparsely fossiliferous shale bed. When traced laterally in section, these distinct layers generally merge into a discontinuous limestone bed, a strong indication that shale layers may represent more than one depositional event. Thin calcareous horizons and localized concentrations of silt are also abundant within the Corryville shale beds and can be best observed in core sections.

Storm beds and amalgamated beds are two types of strata commonly associated with Corryville deposition. Storm beds are tempestites that contain an erosive base and a basal fossiliferous limestone that grades upward into a calcisiltite and then into a planar- to cross-laminated calcareous siltstone (Brandt, 1986). An amalgamated bed is defined as a multiple-event bed that consists of two or more abruptly overlain siltstones or limestones within a single lithified unit. In most amalgamated beds, a basal fossiliferous packstone or grainstone is sharply overlain by a bioturbated, sparsely fossiliferous, calcareous siltstone. The base of the siltstone is commonly planar and may be erosional. Thicker amalgamated beds will contain several overlain packstones or grainstones that display varying degrees of winnowing, sorting, and breakage of fossils. The contacts between these amalgamated lithologies are planar to irregular and commonly contain thin (<1.0 cm/0.4 inch), discontinuous shale interbeds.

Both the upper and lower contacts of the Corryville Member in the southwestern Ohio area range from sharp to gradational and are differentiated by a change in the mean shale percentage, limestone bedding style, shale parting characteristics, and the fossil content of the shales. The underlying Bellevue Member contains a comparatively low mean shale percentage (17-47 percent), irregular- to wavy-bedded limestone, and fissile-parted, fossiliferous shale (Schumacher and others, 1991). The Bellevue-Corryville contact is sharp at the O'Bannon Creek (OH-CT-0008) and Stonelick Creek localities (OH-CT-0004), and has been placed at the lowest typical Corryville limestone or shale bed. Where the Bellevue-Corryville transition is gradational, the accepted procedure is to arbitrarily place the contact midway between the typical unit lithologies (Schumacher and others, 1991).

The overlying Mt. Auburn Member is dominantly fissile-parted, fossiliferous shale (50 percent) and nodular-bedded limestone (Schumacher and others, 1991). The shale contains small, fossiliferous, discontinuous limestone nodules and a very fine fossil detritus, which gives it a characteristically gritty texture. The Corryville-Mt. Auburn contact is placed at the base of the lowest typical Mt. Auburn shale bed or at the top of the highest typical Corryville limestone bed. Due to the high shale content of both the Corryville and the Mt. Auburn Members, sections containing the upper Corryville contact are rarely well exposed; the best examples of this interval can be seen in small stream exposures at the Hunts Creek (OH-BU-0004), Second Creek (OH-WA-0006), and Lick Run (OH-WA-0004) localities. The large, globose, and thick-shelled brachiopod *Platystrophia ponderosa auburnensis*, known locally as the "double-headed Dutchman," is restricted to the Mt. Auburn, and its initial appearance can assist in the placement of the upper Corryville contact.

SITE DESCRIPTIONS

SITE 1: THE CORRYVILLE "TYPE AREA"

About 1900, when the original stratigraphic nomenclature for the Cincinnati area was established, the most convenient outcrops for study were those exposures located within the neighborhoods bordering downtown. Many of the larger local exposures, such as the one at Fairview Park (OH-HA-0001), were actively quarried for limestone, which was used in the construction of local buildings, walls, and public walkways (Hannibal and Davis, 1992).

Nickles (1902) found abundant outcrops of his Corryville Beds in the Corryville, Clifton, Avondale, Walnut Hills, Fairview Heights, and Price Hill communities (fig. 9-2), apparently enough exposures upon which to recognize the unique lithology and paleontology of the interval, as well as its general stratigraphic position. However, Nickles' (1902) original Corryville description did not designate a specific type section for the unit; hence, these Cincinnati communities, and especially Corryville, have been adopted as an informal "type area" for the unit. This "type area" corresponds to an east-west-trending, present-day topographic high, the result of downcutting by past and present drainage systems. This portion of Cincinnati is represented in portions of four 7.5-minute quadrangles: Cincinnati West (Ohio), Cincinnati East (Ohio), Newport (Ky.–Ohio), and Covington (Ky.–Ohio).

Over the years, Nickles' "type area" has become thoroughly urbanized and, with a few exceptions, all of the oldest Cincinnatian exposures have been either demolished or buried. None of the original Corryville exposures is intact. Records from the fossil collections of the University of Cincinnati place previously existing Corryville localities along the southeast side of Highland Avenue, at the top of Fairview Heights, on McMillan Street east of Reading Road, and behind the Seminole Apartments southwest of the intersection of Ravine and McMillan Streets. Loose slabs of Corryville limestone still can be found within the Corryville area; several possibly in situ limestone beds are exposed in the grass-covered bank on the southern end of University Plaza in the Corryville area. New Corryville exposures occasionally appear as a result of building construction or sewer maintenance, but these are usually of temporary duration.

At the time of this writing, only one fairly clean Corryville exposure is present in the "type area": in the empty lot west of 16 McMillan Street (OH-HA-0027), approximately 66 meters (200 ft) from the intersection of Vine and McMillan Streets in the Corryville area (fig. 9-3). This outcrop is located in a small, paved parking space, and the settled appearance of this site does not suggest immediate plans for construction. The exposure has become fairly weathered in the past few years, but the individual limestone, siltstone, and shale beds are still apparent. The base of this 3-meter (12-ft) exposure lies at an approximate elevation of 845 ft (257.6 meters) above sea level; the section most likely represents the middle to upper portions of the Corryville. An excellent example of an amalgamated bed can be found approximately 0.5 meter (1.6 ft) from the base of the exposure. The basal half of this 12-cm-thick (5-inch-thick) bed is a coarse, fossiliferous grainstone. The upper portion of the bed consists of a calcisiltite with an erosive base that fines upward into a cross-laminated and slightly bioturbated siltstone.

The contact between the Bellevue and the Corryville Mem-

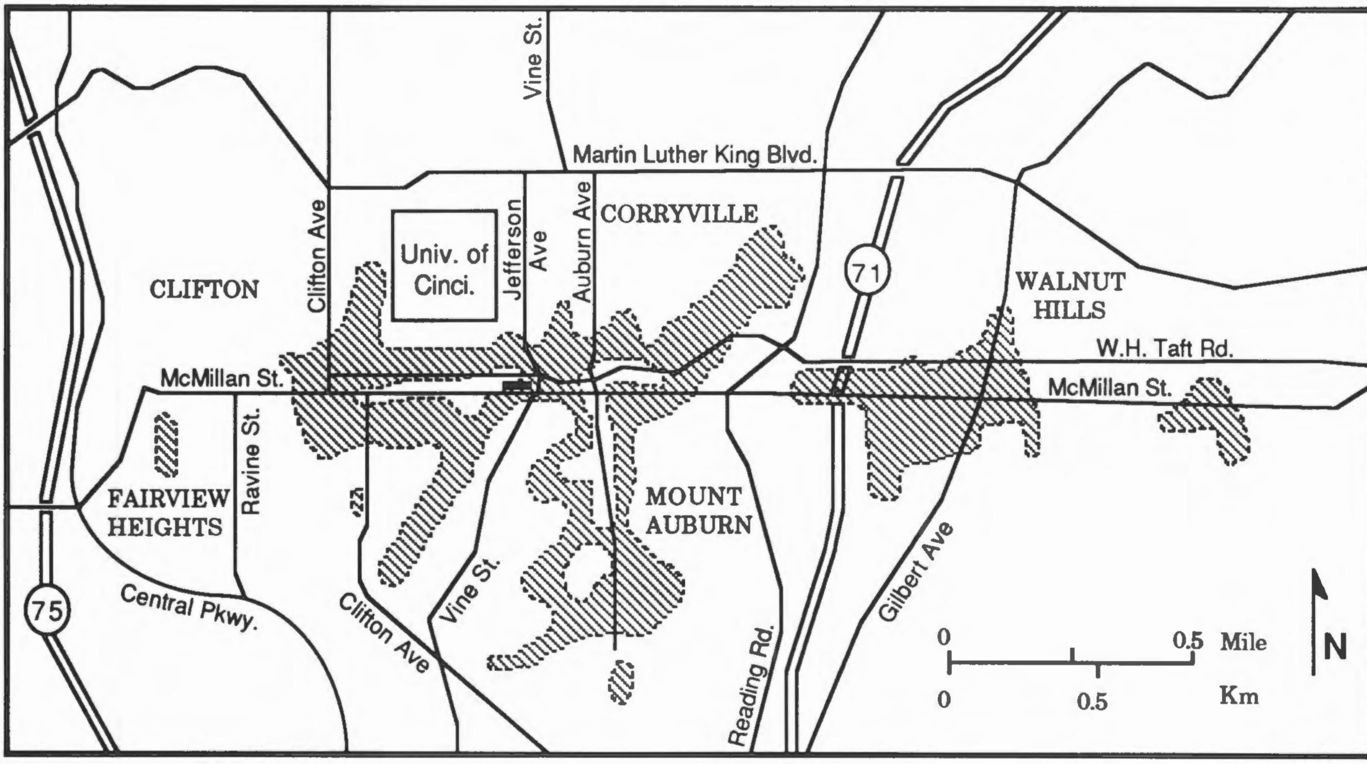


FIGURE 9-2.—Location of the Corryville "type area" in Cincinnati, Ohio. The line pattern indicates the area in which the Corryville Member should be the surface bedrock. This area corresponds to elevations between 820 and 865 ft (249.9 and 263.7 meters) above sea level. The small black rectangle marks the location of the McMillan Street exposure (OH-HA-0027) in figure 9-3. The Avondale neighborhood is north of Corryville. The Price Hill neighborhood is southwest of the area shown on this map.

FIGURE 9-3.—A "type" Corryville exposure in the empty, south-facing lot just west of 16 McMillan Street in Cincinnati, Ohio (OH-HA-0027).

bers can be seen in two partially buried exposures, one atop the cliff at the southwestern corner of Bellevue Hill Park (OH-HA-0003), and the other at the top of the small Bellevue exposure just below the transmitting tower above Emming Street (OH-HA-0002). This contact corresponds roughly to an elevation of 820 ft (250.0 meters) above sea level. Although the shales at these sites are buried or recessed, there is an obvious transition from irregular-bedded, brachiopod-rich limestones that contain randomly oriented fossils (Bellevue) to planar-bedded limestones that incorporate subhorizontally oriented fossils that each have a silt cap containing convex-up *Rafinesquina* (Corryville).

The Mt. Auburn contact is not exposed in Cincinnati. Given an approximate thickness of 44 ft (15 meters) in the type area (Caster and others, 1955), the expected elevation for this contact is about 865 feet (264 meters) above sea level. This estimate is corroborated by the comparatively higher elevations of previously existing Mt. Auburn exposures. Given boundary elevations and past and present outcrop sites, a bedrock map can be constructed for the prediction of potential Corryville exposures within the type area (fig. 9-2).

SITE 2: STONELICK CREEK, THE PROPOSED "TYPE SECTION"

Location

Stonelick Creek (OH-CT-0004; fig. 9-4) contains a composite section of the entire Corryville and has been proposed as the official type section for the Corryville Member of the Grant Lake Formation (Schumacher and others, 1991). The Corryville is present in a series of discontinuous stream cuts upstream and downstream of the Ohio Route 131 bridge (39°10'40"N latitude, 84°06'43"W longitude; Newtonsville, Ohio, 7.5-minute quadrangle), Stonelick Township, Clermont County, Ohio, about 1.3 miles (2.2 km) west of the center of Newtonsville, Ohio, about 9.3 miles (15.5 km) east of the city limits of Milford. Corryville exposures range in height from 0.6 meter (2.0 ft) to 18.0 meters (59.0 ft) and occur along both sides of the creek from 1,000 ft (305 meters) north to 1.4 miles (2.3 km) south of the bridge. Two measured sections from Stonelick Creek are on file at the Ohio Geological Survey; measured section no. 16836 represents the lower half of the Corryville, and measured section no. 16837 contains the upper two-thirds of the Corryville Member. Contacts with the underlying Bellevue and the overlying Mt. Auburn Members of the Grant Lake Formation are present, although the latter contact is more gradational and is not exposed well in any single outcrop. Permission to traverse the creek south of the Ohio Route 131 bridge should first be obtained from the landowner at the farm located at 6028 S. Manila Road, just west of the creek. A private lane runs from the landowner's property south along the creek and provides ready access to the lowermost Corryville sections and to the contact with the Bellevue Limestone.

Discussion

Stratigraphic variations within the Corryville section are best understood from cores and from stream outcrops located outside of the Cincinnati area. Stonelick Creek is the most complete and best known Corryville exposure in southwestern Ohio. Most of the rare macrofossil and ichnofossil species attributed to the Corryville have been collected at this site, either in situ from the creek banks or from the loose material lying in the creek bed. Periodic flooding in the spring and fall maintains clean exposures, and new fossil material is continually weathering out of the rock. Water levels at Stonelick Creek remain low throughout most of the summer, fall, and early winter.

The entire Corryville section is exposed at Stonelick Creek.

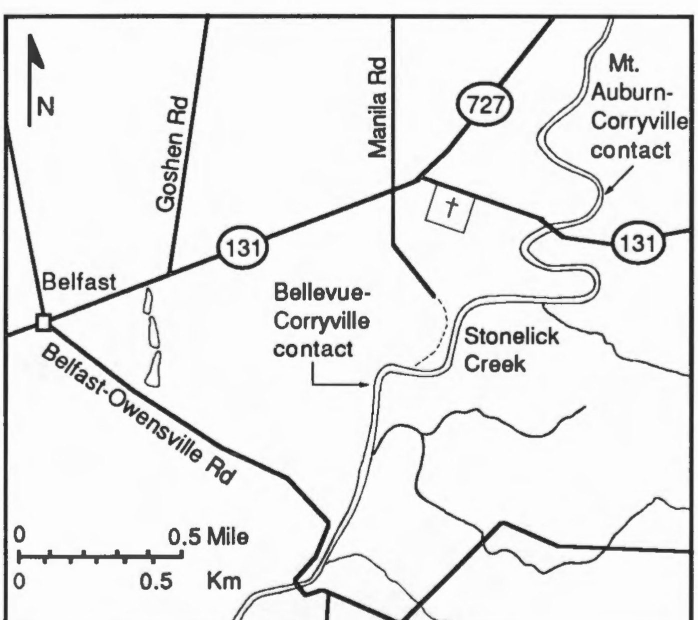


FIGURE 9-4.—Location of Stonelick Creek (OH-CT-0004) in Clermont County, Ohio. Corryville exposures occur along the creek from 1,000 feet (0.3 km) north to 1.4 miles (2.3 km) south of the Ohio Route 131 bridge.

The lateral continuity of stream cuts facilitates the correlation of meter-scale or larger depositional trends and of smaller lithologically and paleontologically distinct strata. The mean shale percentage at Stonelick Creek is 59 percent, slightly less than the regional average (63 percent). The Corryville Member is approximately 19.4 meters (63.6 ft) thick at this locality (fig. 9-5). Previous estimations of overall unit thickness (Hinterlong, 1981; Schumacher, 1984) differ slightly from this measurement, which is ultimately dependent upon the placement of the gradational upper contact. The contact with the underlying Bellevue Member is also gradational and has been arbitrarily placed at the lowest thick, planar-bedded fossiliferous grainstone. This bed tends to form ledges and is best seen in the southernmost prominent east-facing exposure along the creek (fig. 9-6), about 1.4 miles (2.3 km) south of the Ohio Route 131 bridge, where the creek makes a sharp southward bend. The Fairview Formation below the Bellevue Member is exposed farther downstream, at the Belfast-Owensville Road bridge. The upper contact with the Mt. Auburn Member occurs north of the Ohio Route 131 bridge or near the tops of the highest creek exposures. This contact is gradational and cannot be seen in any single creek-level exposure.

The Corryville Member can be subdivided into four distinct vertical "zones" (fig. 9-5) distinguished by variations in mean shale percentage and shale and limestone lithology. The lowest zone, "Zone 1," is approximately 8.9 meters (29.2 ft) thick and extends upward from the lower contact with the Bellevue. It can be examined best in the first wide, west-facing exposure upstream of the Bellevue contact. This zone is dominated by thick (6 cm/2.4 inches average), continuous to discontinuous packstones, grainstones, and calcisiltites. Shales are slightly fossiliferous, average 6 cm (2.4 inches) in thickness, and account for 54-59 percent of this zone. The brachiopods *Platystrophia* and *Rafinesquina nasuta* are primarily restricted to this zone. The trace fossils *Diplocraterion*, *Trichophycus*, and *Chondrites* type B (Osgood, 1970) are abundant in the calcisiltites and in the silty tops of the limestones. Bedding contacts are mostly planar, with the exception of three separate, distinct, laterally persistent, irregular-bedded packstones. These strata contain abundant randomly oriented shells (*Platystrophia*, *Rafinesquina*) and large, broken ramose bryozoans and are interbedded with fissile, fossiliferous shales that contain small, fossiliferous limestone nodules. The largest of the intervals is 0.5 meter (1.6 ft) thick and is located approximately 5.5 meters (18.0 ft) above the Bellevue contact.

"Zone 2" extends from 8.9 to 10.0 meters (29.2 to 32.8 ft) above the Bellevue contact and is characterized by thick, sparsely fossiliferous shales (8 cm/3 inches average thickness) and interbedded thin calcisiltites, siltstones, and wackestones (4 cm/1.6 inches average thickness). This zone is shale rich (65-72 percent) and is capped by a continuous 12-to-19-cm-thick (4.7- to 7.5-inch-thick) limestone bed that varies lithologically from a poorly washed grainstone to a packstone. Shales may exceed a thickness of 34 cm (13.4 inches). Soft, yellow, discontinuous shales, commonly referred to as "butter shales" or "trilobite shales" (Brandt, 1980; Velbel, 1985), occur in this zone; these fine-grained layers are the source of abundant extended and enrolled specimens of *Flexicalymene* and *Isotelus* (fig. 9-7). Enrollment may have been an instinctive response to deep and abrupt burial, after which the organisms, unable to escape, were preserved articulated and in situ (Brandt Velbel, 1985). Rock of "Zone 2" can be seen in a 3-meter-high (10-ft-high) north-facing exposure 600 meters (1,970 ft) south of the Ohio Route 131 bridge.

"Zone 3" extends from 10.1 to 13.5 meters (33.1 to 44.3 ft) above the Bellevue contact and is characterized by a lower mean shale percentage (55 percent), thinner shale beds (6 cm/2.4 inches average), and an increased number of packstones and amalgamated beds. Amalgamated beds are abundant in the upper half of this zone and may account for up to 45 percent of all beds in this interval. The lower 1.0 meter (3.3 ft) of this zone is dominated by calcisiltites and calcareous siltstones, and "trilobite shales" are present. Trace fossils are abundant in the siltstones and silty bed tops of strata within this zone. "Zone 3" can be examined at the first north-facing exposure south from the Ohio Route 131 bridge and just beyond the point where the creek bends 90° to the east.

"Zone 4" extends from 13.6 to 19.4 meters (44.6 to 63.6 ft) above the Bellevue contact (to the Mt. Auburn contact), has a mean shale percentage of 63-67 percent, and is thicker and shalier than is "Zone 3." Shales average 9 cm (3.5 inches) in thickness and are sparsely fossiliferous, although fossil content does increase with proximity to the contact with the Mt. Auburn Member. "Zone 4" can be subdivided into four stacked bedding sequences that are similar to "Zone 2" in size and lithology (fig. 9-5). Each shale-rich sequence ranges from 1 to 2 meters (3 to 6 ft) in thickness and contains thin (3 cm/1.2 inches average) and continuous calcisiltites, siltstones, and fossiliferous packstones. The calcisiltites and siltstones are planar- to wavy-bedded and commonly are laminated and display sole marks. The top of each sequence is delineated by a prominent and thick (15 to 41 cm/5.9 to 16.1 inches) amalgamated bed composed of two to four irregular- to planar-bedded grainstones and packstones with two or more thin, discontinuous shale interlayers. "Zone 4" can be seen complete in the higher cliffs along the creek, specifically the steep west-facing exposure at the first 180° creek bend south of the Ohio Route 131 bridge.

PALEONTOLOGY

The Corryville is widely known and appreciated for its abundant and well-preserved open-marine fossil assemblage, the most diverse of any stratigraphic unit of the Cincinnatian Series. The limestones in the stratigraphic center of the Corryville Member have the highest generic diversity (number of genera/square meter) (Hinterlong, 1981). The macroinvertebrate fauna includes articulate and inarticulate brachiopods, bryozoans, pelecypods, gastropods, trilobites, orthoconic nautiloids, crinoids, and other echinoderms (table 9-1). Most abundant are trilobite fragments (*Flexicalymene*, *Isotelus*); crinoid columnals; thin, smooth ramose bryozoans; and the brachiopods *Rafinesquina* and *Zygospira*. Pelecypods are commonly preserved as molds. Less common Corryville taxa include ostracodes, conodonts, graptolites, scolecodonts, conularids, and *Cornulites*. Rare fossils in the Corryville include edrioasteroids (fig. 9-7.8), asteroids, the carpoid *Enoploura popei* (Caster, 1952) (fig. 9-7.3), and *Neostrabops martini* (Caster and Macke, 1952), the only aglaspid known from the Cincinnatian (fig. 9-7.2). *Enopleura popei* and *N. martini* are known only from the Corryville, *N. martini* only from the Stonelick Creek locality.

Escape structures and other ichnofossils are present and abundant throughout the Corryville (Osgood, 1970; Meyer and others, 1981). These trace fossils are almost always re-

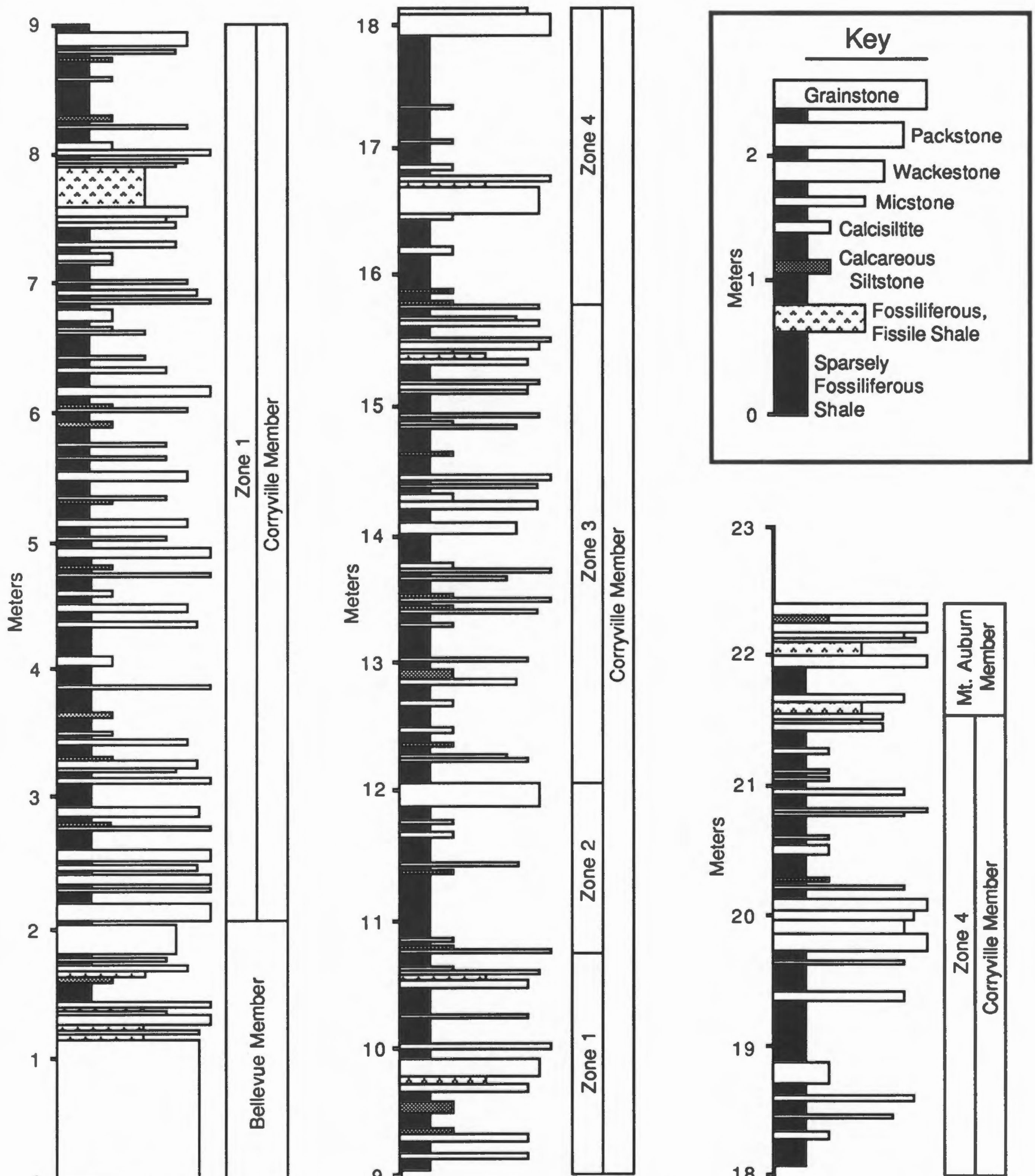


FIGURE 9-5.—Composite stratigraphic column of the Corryville Member of the Grant Lake Formation (Upper Ordovician) from Stonelick Creek (OH-CT-0004) in Clermont County, Ohio.

FIGURE 9-6.—Exposure of the Bellevue-Corryville contact at Stonelick Creek in Clermont County, Ohio (OH-CT-0004). The base of the Corryville is placed at the thick, ledge-forming grainstone near the center of the exposure.

TABLE 9-1.—*Faunal list of the Corryville Member of the Grant Lake Formation*

In the absence of a modern taxonomic listing for the unit, the following informal faunal list has been compiled. All taxa were verified from previous publications, from personal examination of fossiliferous limestone and shale beds, or both. The previous list of Dalvé (1948) is outdated and in need of serious revision.

Taxa	References
	Cnidaria (?)
conulariids	Caster (1942)
	Brachiopoda, Articulata
Hebertella occidentalis	Caster and others (1955), Hinterlong (1981)
Onniella	Tobin (1982)
Plectorthis	Caster and others (1955)
Platystrophia spp. (incl. *P. laticosta* and *P. ponderosa*)	Nickles (1902), Braun (1916), Caster and others (1955), Gutstadt (1958), Carpenter and Ory (1961), Ford (1967), Hinterlong (1981), Tobin (1982)
Rafinesquina alternata	Nickles (1902), Van Fossen (1951), Hinterlong (1981), Schumacher (1984), Meyer (1990)
Rafinesquina nasuta	Nickles (1902), Van Fossen (1951), Caster and others (1955), Carpenter and Ory (1961)
Zygospira modesta	Meyer and others (1981), Hinterlong (1981), Tobin (1982), Schumacher (1984)
	Brachiopoda, Inarticulata
Schizocrania filosa	Nickles (1902), Caster and others (1955)
Trematis millepunctata	Nickles (1902), Caster and others (1955), Schumacher (1984)

TABLE 9-1.—*continued*

Taxa	References
	Bryozoa
Amplexopora	Hinterlong (1981)
Batostomella gracilis	Caster and others (1955), Tobin (1982)
Chiloporella nicholsoni	Nickles (1902), Braun (1916), Caster and others (1955), Gutstadt (1958), Hinterlong (1981), Tobin (1982)
Dekayia	Nickles (1902), Caster and others (1955), Hinterlong (1981), Tobin (1982)
Heterotrypa	Nickles (1902), Gutstadt (1958), Hinterlong (1981)
Homotrypa	Caster and others (1955)
Monticulopora	Nickles (1902), Caster and others (1955), Hinterlong (1981), Tobin (1982)
Parvohallopora ramosa	Caster and others (1955), Gutstadt (1958)
	Annelida
scolecodonts	Schumacher (1984)
	Arthropoda, Aglaspida
Neostrabops martini	Caster and Macke (1952), Hinterlong (1981)
	Arthropoda, Ostracoda
ostracodes	Dalvé (1948), Tobin (1982)
	Arthropoda, Trilobita
Acidaspis	Hinterlong (1981)
Amphilichas halli	Dalvé (1948)
Ceraurus milleranus	Nickles (1902), Caster and others (1955)
Flexicalymene (incl. *F. meeki*)	Caster and others (1955), Hinterlong (1981), Tobin (1982), Schumacher (1984), Frey (1987b)
Isotelus	Caster and others (1955), Hinterlong (1981), Schumacher (1984), Frey (1987b)
	Mollusca, Cephalopoda
Cameroceras	Dalvé (1948 as *Endoceras*), Frey (1987b)
Oncoceras	Frey (1987b)
Treptoceras	Dalvé (1948), Frey (1987b)
	Mollusca, Gastropoda
Bellerophon	Nickles (1902)
Cyclonema	Nickles (1902), Tobin (1982), Schumacher (1984)
Cyclora	Tobin (1982)
Loxoplocus bowdeni	Caster and others (1955), Tobin (1982)
	Mollusca, Monoplacophora
Cyrtolites	Dalvé (1948)
	Mollusca, Pelecypoda
Ambonychia (incl. *Byssonychia*)	Nickles (1902), Braun (1916), Pojeta (1962), Tobin (1982), Schumacher (1984), Frey (1987a, b)
Anomalodonta	Braun (1916), Frey (1987a)
Caritodens demissa	Pojeta (1971), Schumacher (1984), Frey (1987a)
Cleidophorus	Frey (1987a)
Corallidomus	Frey (1987a, b)
Ctenodonta	Frey (1987a)
Cuneamya	Frey (1987a)
Cycloconcha	Frey (1987a)
Cymatonota	Frey (1987a)
Deceptrix	Frey (1987a)
Lyrodesma	Frey (1987a)
Modiolopsis	Nickles (1902), Schumacher (1984), Frey (1987a)
Orthodesma	Frey (1987a, b)
Pholadomorpha	Frey (1987a)
Psiloconcha	Frey (1987a)
Rhytima	Frey (1987a)
	Echinodermata, Asteroidea
Promopalaeaster	Schumacher (1984)

Taxa	References
	Echinodermata, "Carpoidea"
Enoploura popei	Caster (1952), Hinterlong (1981)
	Echinodermata, Crinoidea
Anomalocrinus	Nickles (1902)
Cincinnaticrinus	Dalvé (1948)
Iocrinus (incl. *I. subcrassus*)	Hinterlong (1981), Meyer and others (1981), Schumacher (1984), Frey (1987b)
"Lichenocrinus"	Nickles (1902), Caster and others (1955)
Ohiocrinus	Nickles (1902)
Pycnocrinus (Including what is commonly called *Glyptocrinus dyeri*)	Nickles (1902), Caster and others (1955), Hinterlong (1981), Meyer and others (1981), Schumacher (1984), Frey (1987b)
	Echinodermata, Edrioasteroidea
Carneyella pilea	Caster and others (1955), Bell (1972, 1976), Meyer and others (1981), Meyer (1990)
Isorophus cincinnatensis	Foerste (1914), Caster and others (1955), Kesling and Mintz (1960), Bell (1972, 1976), Meyer and others (1981), Meyer (1990)
Streptaster vorticellatus	Bell (1972), Meyer and others (1981), Meyer (1990)
	Hemichordata, Graptolithina
graptolites	Schumacher (1984), Bergström and Mitchell (1986)
	Trace fossils
Asteriacites stelliforme	Osgood (1970), Meyer and others (1981)
Chondrites type B	Osgood (1970), Hinterlong (1981), Meyer and others (1981), Tobin (1982, 1986)
Diplocraterion biclavatum	Osgood (1970), Hinterlong (1981), Meyer and others (1981), Tobin (1982, 1986)
Fascifodina floweri	Osgood (1970), Meyer and others (1981)
Lockeia siliquaria	Osgood (1970), Meyer and others (1981)
Palaeophycus type B	Osgood (1970), Hinterlong (1981), Meyer and others (1981), Tobin (1982, 1986)
Palaeoscia floweri	Caster (1942), Osgood (1970), Hinterlong (1981)
Phycodes flabellum	Osgood (1970), Meyer and others (1981)
Rusophycus carleyi	Osgood (1970), Meyer and others (1981)
Rusophycus pudicum	Osgood (1970), Hinterlong (1981), Meyer and others (1981)
Trichophycus venosum	Osgood (1970), Hinterlong (1981), Meyer and others (1981), Tobin (1982, 1986)
"escape structures"	Tobin (1982)
	Other
conodonts	Bergström and Mitchell (1986)
Cornulites corrugatus	Schumacher (1984)
Lepidocoleus (machaeridian)	Dalvé (1948), Schumacher (1984)

stricted to the siltstones, calcisiltites, silty tops of beds, and the more silty portions of amalgamated beds. Common trace fossils include *Chondrites* type B (fig. 9-7.6), *Trichophycus venosum* ("turkey tracks") (fig. 9-7.5), and *Diplocraterion biclavatum* (the "dumbbell" U-shaped burrow); these particular ichnofossils commonly occur in association in the thicker calcareous siltstone layers. Less common ichnofossils are *Lockeia siliquaria*, *Asteriacites stelliforme* (an impression of an asteroid echinoderm), *Phycodes flabellum*, *Paleophycus* type B, *Rusophycus carleyi*, and *Rusophycus pudicum*. *Rusophycus carleyi* and *R. pudicum* have been interpreted as the resting and feeding traces of *Isotelus* and *Flexicalymene*, respectively (Osgood, 1970). All three known specimens wherein a *Flexicalymene* was found in situ within a *R. pudicum* burrow were discovered from the Corryville section of Stonelick Creek (Osgood, 1970). Unique to the Corryville are *Fascifodina floweri*, a vertical bundle of tunnel systems set in a semi-elliptical pattern, and *Palaeoscia floweri*, a series of regular to irregular concentric circles marked by a central pore (Osgood, 1970). *Conostichus*, a conical, convex hyporelief believed to be a sea-anemone burrow (Pemberton and others, 1988), is present in calcisiltites and siltstones within the 2 meters (6.6 ft) of section below the upper Corryville contact.

Corryville fossils exhibit a variety of preservational modes, from original shell material to molds. Individual brachiopod shells range in appearance from pristine to fragmented to heavily encrusted and bored. Disarticulated trilobite and crinoid fragments are common, but show little to no abrasion and corrosion, implying little transport and a parautochthonous origin. Fossil orientation within and at the surface of beds is dominantly subhorizontal, but may in places become imbricated or shingled or may display no preferential orientation at all. The upper bedding surfaces of many of the packstones and grainstones exhibit abundant whole or disarticulated convex-up pelecypod and brachiopod shells, commonly referred to as shell "pavements." The shells of one *Rafinesquina* pavement display a strongly bimodal NE-SW orientation that has been attributed to a preburial storm surge in the same direction (Meyer, 1990).

FIGURE 9-7.—Fossils of the Corryville Member of the Grant Lake Formation. UCGM = University of Cincinnati Geology Museum.

1 *Chiloporella nicholsoni*, UCGM uncatalogued specimen, X1. Nickles (1902) gave the authorship of this species as "(James)," but Bassler (1915) gave it as Nickles and Bassler, 1900, and specifically did not recognize *Ceramopora nicholsoni* U. P. James, 1875.

2 *Neostrabops martini* Caster and Macke, 1952, dorsal view of holotype, UCGM 25569, X1.

3 *Enoploura popei* Caster, 1952, convex (? dorsal) side of carapace, holotype, UCGM 25993, X1.

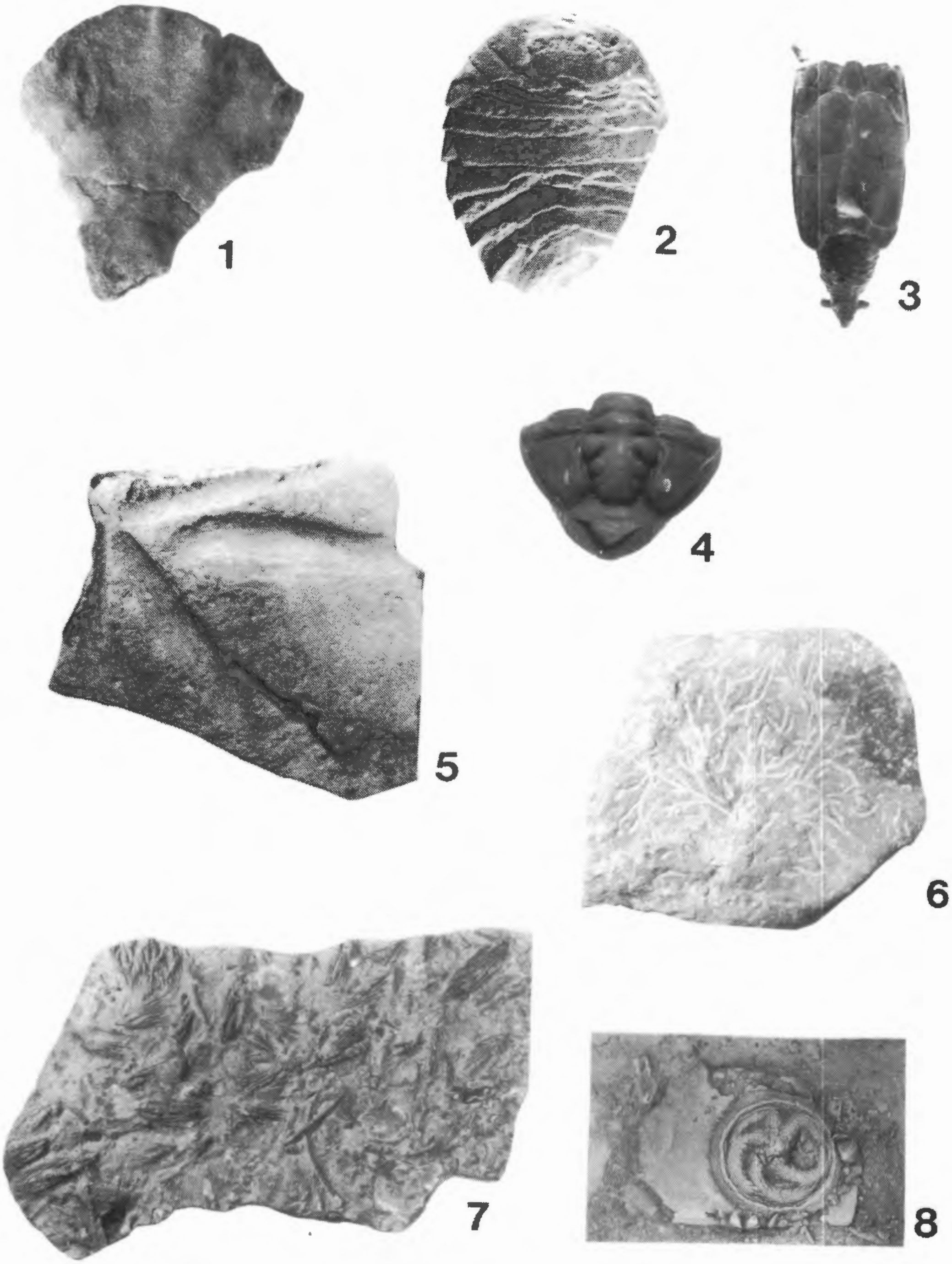
4 *Flexicalymene meeki* (Foerste, 1910), enrolled specimen from Stonelick Creek, Clermont County, Ohio, X1.

5 *Trichophycus venosum* (Miller), three specimens on siltstone, X0.2.

6 *Chondrites* type B Osgood, 1970, X0.25.

7 *Iocrinus subcrassus* (Meek & Worthen, 1865), uppermost Corryville, UCGM 44362, X0.25.

8 *Isorophus cincinnatiensis* (Roemer), on valve of brachiopod shell, X1.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Brachiopods, with the exception of *Platystrophia*, are dominantly thin shelled and are commonly preserved as unbroken valves with little to no corrosion or abrasion. Byrozoan morphology is dominated by small- to medium-sized ramose colonies, but foliate and encrusting varieties are plentiful as well. Massive foliate and ramose bryozoan colonies over 30 cm (1 ft) in diameter can be found intact in limestones and shales; most of these are overturned and exhibit multiple surface borings.

PALEOENVIRONMENTAL INTERPRETATION

Certain taphonomically unique Corryville beds have been ascribed directly to storm-related, catastrophic burial (Brandt, 1980; Meyer and others, 1981; Brandt Velbel, 1985; Meyer, 1990). Examination of these deposits has produced a wealth of paleoecological data concerning the population composition, size-frequency distribution, preferred life mode, and substratum preference of Late Ordovician invertebrates. In addition, paleoenvironmental data, including current orientation, amount of preburial transport, surface exposure time, and burial timing and conditions, can be interpreted from these deposits. These beds have been dually categorized as "event beds" (strata attributed to rapid and episodic sedimentation) and "Fossil-Lagerstätten" (unique, well-preserved fossil assemblages that yield an unusual amount of paleontological and taphonomic information). Examples of such "event beds" include deposits containing abundant, articulated *Iocrinus subcrassus* (fig. 9-7.7) collected from siltstones just below the Corryville-Mt. Auburn contact (Schumacher, 1984) and the aforementioned "trilobite shales." "Fossil-Lagerstätten" is an appropriate description for the abundant, articulated edrioasteroids (*Isorophus*, *Streptaster*, and *Carneyella*) discovered intact on *Rafinesquina* shells atop two upper Corryville brachiopod shell pavements (Meyer and others, 1981; Meyer, 1990) (fig. 9-7.8). Rassman (1981), in a study of one of these pavements, concluded that it was an incipient hardground formed by early diagenetic marine cementation.

The Corryville Member of the Grant Lake Formation has been interpreted as having been deposited in an offshelf environment situated along a gently sloping, west-facing carbonate ramp in a shallow epeiric sea (Tobin, 1982). The Corryville represents an offshore facies situated at the base of a third-order shoaling-upward cycle; its lower contact with the Bellevue Member marks the beginning of an abrupt transgression from a more shallow, turbulent depositional environment to a comparatively deeper water environment (Tobin, 1982; Tobin and Pryor, 1985). The relative abundance of siltstones and shales, the relative thickness of the shale beds, the excellent preservation of trace fossils and sedimentary structures, and the abundance of whole, unabraded, thin-shelled and delicate invertebrate macrofossils all indicate low-energy deposition, probably below wave base, in a protected, quiet-water environment (Tobin, 1982). Depositional trends related to the eastward shallowing of the ramp include a decrease in Corryville shale content and average shale thickness toward the south and east and an increase in the abundance of grainstones to the south and east (Tobin, 1982; Schumacher and others, 1991).

Corryville deposition was dominated by episodic storm events (Tobin, 1982). The large numbers of storm beds, amalgamated beds, and current-oriented, storm-related sedimentary structures support this interpretation. Limestones are most likely parautochthonous tempestites; grainstones are indicative of proximal deposition, and siltstones and calcisiltites are representative of distal deposition (Tobin, 1982). Taphonomic evidence from smothered hardgrounds and the "trilobite shales" indicates that shale deposition was, at least at times, both rapid and episodic (Brandt, 1980; Meyer and others, 1981; Brandt Velbel, 1985; Meyer, 1990) and that some shale beds record more than one depositional event. The four zones evident at Stonelick Creek are distinct lithologically and paleontologically and can be correlated in field exposures and core sections in southwestern Ohio. The existence of such traceable zones implies temporal variations in depositional environment on a regional scale. Small-scale bedding cycles in the Kope and Fairview Formations, lower in the Cincinnatian, have been attributed to fluctuations in absolute sea level (Jennette, 1986). Such fluctuations also may been the cause of depositional variations in the Corryville Member.

ADDITIONAL CORRYVILLE LOCALITIES

The following list is divided into two parts, one for the Grant Lake Formation and the second for the Grant Lake Limestone, as used by the Ohio Division of Geological Survey. For more information on a given site, see Appendix A at the end of this volume.

CORRYVILLE MEMBER OF GRANT LAKE FORMATION

Bellevue Hill (OH-HA-0003). Partial exposure at top of cliff at the southwestern corner of park. The Bellevue-Corryville contact is present at this site and is set at a prominent limestone bed which forms a small ledge near the cliff edge. Corryville limestones display a distinctive silt covering on the bed top and convex-up brachiopods. Most shales are recessed or buried.

Blue Rock Road (OH-HA-0005). Between 1.0 meter (3.3 ft) and 3.9 meters (12.8 ft) of Corryville is present, but mostly buried, at the base of the cut. The upper 7.6 meters (25.0 ft) of section is composed of the Mt. Auburn Member and the Sunset Formation. Both a shell pavement with abundant edrioasteroids and a horizon containing abundant specimens of the crinoid *Iocrinus subcrassus* have been excavated from the Corryville section at this site (Meyer, 1990; Schumacher, 1984).

"Big 4" railroad cut (Maud cut) (OH-BU-0002). Most of this exposure is Mt. Auburn, but Corryville limestones can be found at the base of two cliffs along the tracks.

Dornbusch (OH-HA-0026). This section contains 11.2 meters (36.7 ft) of the Corryville Member.

Elk Creek (OH-BU-0003). This stream cut exposes 5.5 meters (18.0 ft) of the Corryville interval.

Emming Street (OH-HA-0002). The Bellevue-Corryville contact is present, but partially buried. Corryville limestones are exposed in the small clearing on top of the small west-facing cliff exposure.

Hunts Creek (OH-BU-0004). This locality contains the upper 7.4 meters (24.2 ft) of the Corryville Member, the Corryville-Mt. Auburn contact, and 1.3 meters (4.3 ft) of the Mt. Auburn Member.

Lick Run (OH-WA-0004). The contact with the overlying Mt. Auburn is present and sharp; the contact is best seen in the westernmost north-facing exposure.

Middletown (OH-BU-0005). The Corryville is present in the lower 5.0 meters (16.4 ft) of the road cut. The lower half of the section, including the Corryville-Mt. Auburn contact, is partially buried underneath a layer of talus. This locality is the type section for Hay's (1981) "Excello member" of the "Brookville formation," referred to as the "Excello" locality.

Muddy Creek (OH-HA-0020). Most of this exposure in the stream cut just south of Muddy Creek Road bridge is the Bellevue Member, but the Bellevue-Corryville contact occurs near the top of the exposure.

O'Bannon Creek (OH-CT-0008). The Bellevue-Corryville contact is present about 4 meters above the stream bed and is sharp. This Corryville exposure contains nearly all of the first "zone." The 0.5-meter (1.6-ft) irregular-bedded horizon is located 5.5 meters (18.0 ft) above the Bellevue-Corryville contact, the same stratigraphic position as at Stonelick Creek.

Ravine Street (OH-HA-0028). A few small Corryville slabs are present and loose in this poor, mostly buried exposure behind the Seminole Apartments southwest of the intersection of Ravine and McMillan Streets in Cincinnati.

Rumpke Landfill (OH-HA-0029). Inaccessible exposure in a field east of U.S. Route 27 N (Colerain Avenue). The almost 14 meters (46 ft) of Corryville and the Corryville-Mt. Auburn contact once were exposed here, but have been buried as a result of landfill activity.

Second Creek (OH-WA-0006). The uppermost Corryville interval and the Corryville-Mt. Auburn contact are present at a small waterfall close to the Cozzandale Road bridge. The Mt. Auburn is well exposed northeast of the bridge just around the first stream meander.

Sharonville (OH-HA-0030). The Corryville can be seen best at the easternmost side of the field just above the highest zone of light-gray, sparsely fossiliferous Miamitown Shale.

Sheits Road (OH-HA-0023). This locality exposes 12.8 meters (42 ft) of the Bellevue Member, the Bellevue-Corryville contact, and 5.6 meters (18.4 ft) of the lower Corryville.

Todd Run (OH-CT-0009). 6.4 meters (21.0 ft) of the Corryville Member are exposed in the stream cut.

West Middletown (OH-BU-0006). Exposed here are 5.0 meters (16.4 ft) of Corryville section, overlain by 5.2 meters (17.1 ft) of the Mt. Auburn Member.

Westwood-Northern Boulevard (OH-HA-0031). Many of the beds in this exposure are thick calcisiltites; this interval may represent the upper Corryville.

Wynbrook Apartments (OH-HA-0025). Exposed here are rocks of the Miamitown Shale and the Bellevue, Corryville, and Mt. Auburn Members of the Grant Lake Formation. The Corryville begins at the first bench up from the parking-lot level.

CORRYVILLE MEMBER OF GRANT LAKE LIMESTONE

Eagle Creek (OH-BR-0005). This section begins at stream level approximately 795 ft (242.3 meters) above sea level. The exposure contains 3.4 meters (11.2 ft) of the Corryville Member, the contact of the Corryville and the overlying Straight Creek Member (Mt. Auburn equivalent), and 5.5 meters (18.0 ft) of the Straight Creek Member.

Georgetown (OH-BR-0006). The Grant Lake Limestone is 28.8 meters (94.4 ft) thick at this locality and complete; the contact with the overlying Bull Fork Formation is gradational, and the contact with the underlying Fairview Formation is sharp (Lee, 1974).

Goose Run (OH-BR-0007). This series of stream cuts exposes the uppermost 4.0 meters (13.1 ft) of the Corryville Member, the contact of the Corryville and overlying Straight Creek Member (Mt. Auburn equivalent), and 5.5 meters (18.0 ft) of the Straight Creek Member.

Manchester (OH-AD-0003). Exposed in this road cut is the contact with the overlying Bull Fork Formation (Lee, 1974); this site is within a few hundred meters of the Isaacs Creek exposure of Sweet (1979).

Ripley #2 (OH-BR-0008). This exposure reportedly exposes a sharp and obvious contact between the even-bedded limestones and shales of the underlying Fairview Formation and the overlying 19.7 meters (64.6 ft) of irregular-bedded Grant Lake Limestone (Lee, 1974).

Sleepy Hollow (KY-MS-0005). This is the type section of the Grant Lake Limestone and is reported to be 33.4 meters (109.6 ft) thick. The upper contact with the Bull Fork Formation and the lower contact with the Fairview Formation are gradational within a 3-meter (10-ft) interval (Lee, 1974).

Thomas More Parkway (KY-KE-0002). This site was exposed in 1989 and consists of three broad benches bounded by several 2- to 3-meter (6- to 10-ft), west-facing exposures. The Bellevue may be present in the lowest exposure.

White Oak Creek (OH-BR-0009). This stream cut exposes 6.5 meters (21.3 ft) of the Corryville Member and begins at stream level, approximately 860 ft (262 meters) above sea level.

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Address of author: Lawrence I. Goldman, MINEsoft, Ltd., 165 S. Union Blvd., #510, Lakewood, CO 80228.

10. THE "BROOKVILLE FORMATION" ("EXCELLO," WAYNESVILLE, AND LIBERTY MEMBERS) AT BON WELL HILL NEAR BROOKVILLE (UPPER ORDOVICIAN, SOUTHEASTERN INDIANA)

by
Helen B. Hay and Roger J. Cuffey

SIGNIFICANCE

The Bon Well Hill road cut (fig. 10-1) exposes the middle portion of the Brookville composite section (fig. 10-2; Hay, 1977, p. I-5 to I-6). In particular, the disconformable contact between the "Excello" and the Waynesville is well exposed here, as well as the middle portion of the "Brookville Formation" of Hay (1981; Hay and others, 1981).

LOCATION

The Bon Well Hill locality (IN-FR-0001) is the long road cut on Indiana Route 101, 1.3-1.7 miles (2.1-2.7 km) northeast of its junction with U.S. Route 52 inside the north edge of Brookville, Franklin County, Indiana (fig. 10-1). The base of the section, at elevation 747 ft (227.7 meters), extends northwestward along the entry road leading to the top of the Brookville Dam. The road cut is in S$\frac{1}{2}$SW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 16, T. 9 N., R. 2 W., Whitcomb, Indiana, 7.5-minute quadrangle, and is centered at 39°26'15"N, 84°59'25"W (4367024 m N, 672966 m E, UTM zone 16).

STRATIGRAPHY AND PALEONTOLOGY

The Bon Well Hill locality was described initially by Hay (1977, p. I-23 to I-26), and later revised and updated by Hay and others (1981, p. 79, 82-84, as Stop 3). The following is taken almost completely from the latter work.

Limestone and shale strata of the "Excello member" of the "Brookville formation" are exposed along the driveway to the dam and at the base of the long section facing Indiana Route 101. Blue-gray shale of the Waynesville Shale Member of the "Brookville formation" occupies most of the section along Route 101. The Liberty Member of the "Brookville formation" occurs at the top of the hill.

The general stratigraphic description and overall faunal chart are provided in figures 10-3 and 10-4, respectively. Discussion of the lithofacies recognized here (fig. 10-5) and stratigraphic nomenclature can be found in Hay (paper 17 in this volume), as well as in Hay (1981). There is a stratigraphic gap of about 9 meters (30 ft) between the top of this road cut and the base of the Garr Hill section (IN-FR-0003) on the basis of study of the continuous exposure at South Gate Hill (IN-FR-0005; see paper 12 in this volume).

Most of the "Excello member" at this outcrop is facies 2b, although the shales are less limy and the limestones less rubbly than they are in the average occurrence of this facies. The other two facies in the "Excello" are 1b with more than 70 percent shale compared with 55-70 percent for facies 2b, and a thin band of facies 3a, cross-bedded calcarenites interbedded with sandy-textured, brown, phosphatic shales at the top of the member. The Waynesville Shale Member contains two intervals of facies 1a separated by a medial band of facies 2a. There is a gradual increase in limestone in the upper half of the outcrop, and the base of the Liberty Member is placed where the shale percentage drops below 70 percent. As figure 10-4 indicates, there are several faunal zones in this outcrop which are related to the lithofacies.

The most interesting question about this section is the nature of the contact between the "Excello" and Waynesville Shale Members and the cause of the abrupt and widespread facies change across the contact. The lower part of the Waynesville Shale Member is nearly devoid of fossils and the few indurated beds in the shales are calcareous siltstones rather than the normal bioclastic limestones. This barren shale overlies the cross-bedded calcarenites at the top of the "Excello," not only at this locality, but throughout most of the northern two-thirds of the outcrop area in southeastern Indiana and southwestern Ohio. This contact is easy to recognize both in cores and in outcrop. Cumings and Galloway (1913) recognized a significant faunal as well as lithologic change across this boundary. It is possible that there is a disconformity between the calcarenites and the basal Waynesville shales, or, alternatively, the disconformity may be just under the calcarenites. In the former case the calcarenites could represent the culmination of the regression, and in the latter case, they could be a basal transgressive "sandstone." If there is a disconformity, then the Waynesville Shale Member is a transgressive unit in which the clastics were derived from erosion of the exposed land, and the absence of fossils is probably due to turbid conditions or unfavorable chemical conditions, perhaps brackish water. The upper half of the Waynesville is much more fossiliferous than the lower half. It contains a diverse molluscan assemblage although brachiopod diversity is low. If this interpretation of the Waynesville Shale Member is correct, then facies 1a in this case represents a different environ-

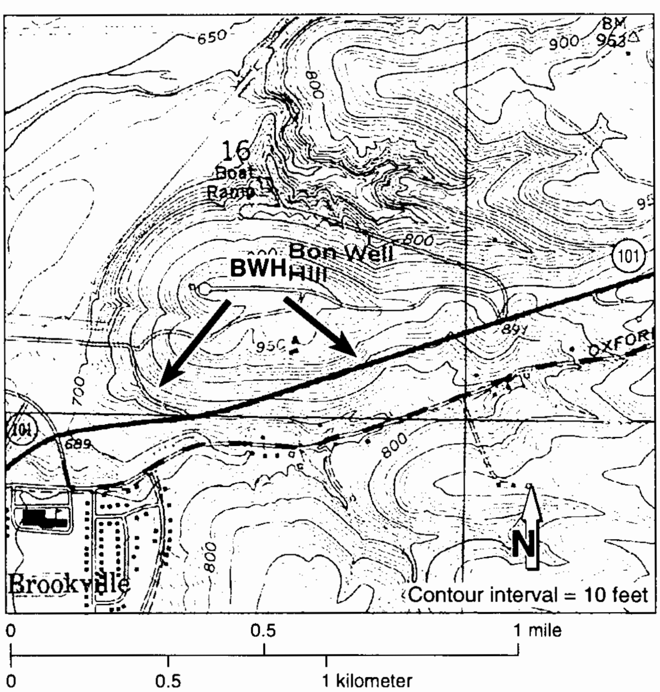

FIGURE 10-1.—Location of the Bon Well Hill road cut (**BWH**; ends indicated by the arrows). Whitcomb, Indiana, 7.5-minute quadrangle.

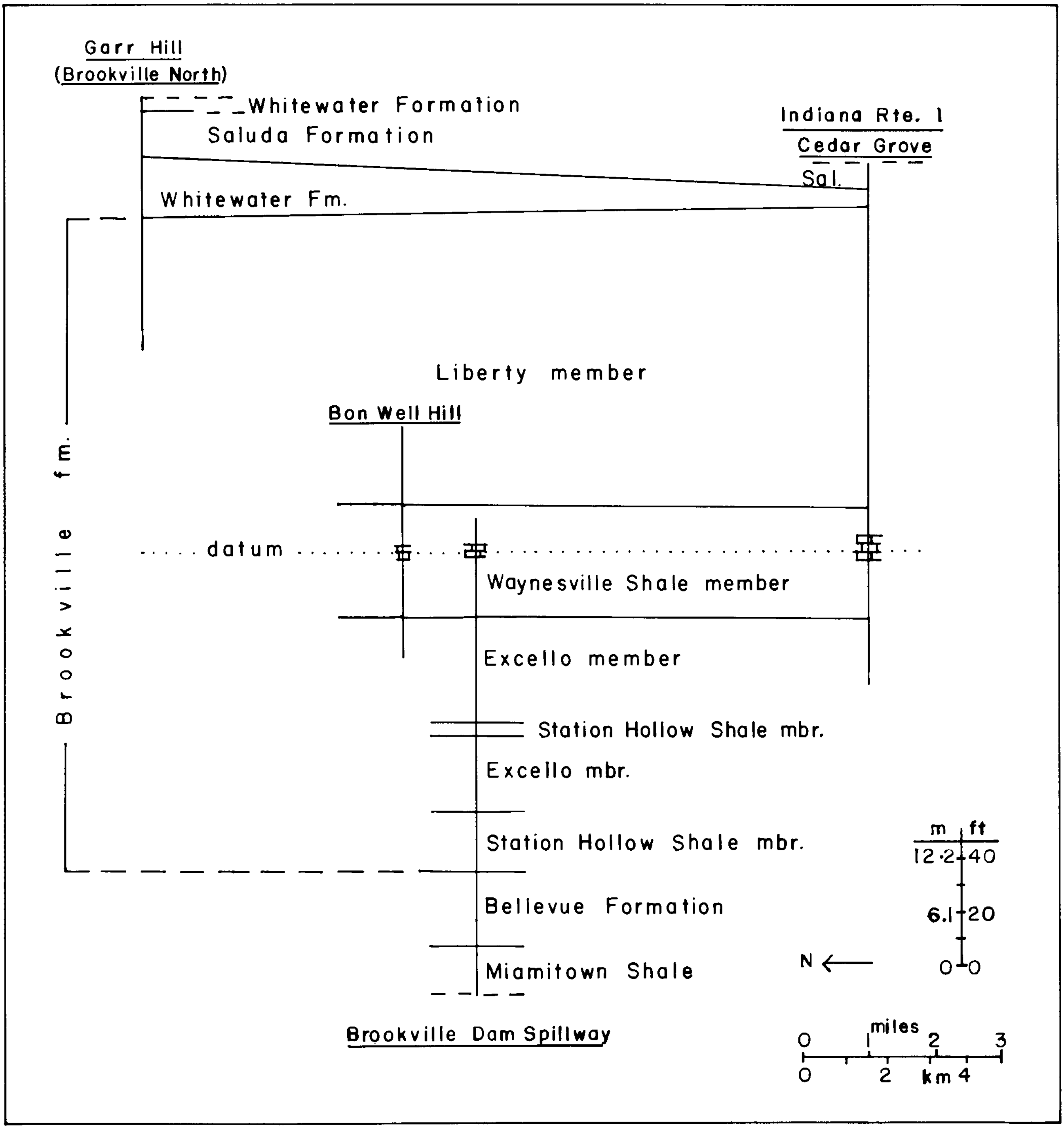

FIGURE 10-2.—Correlation of the four localities that collectively make up the Brookville composite section: Bon Well Hill (IN-FR-0001), Brookville Dam spillway (IN-FR-0002), Garr Hill/Brookville North (IN-FR-0003), and South Gate Hill/Indiana Route 1, labeled as Cedar Grove (IN-FR-0005).

ment than is interpreted for the same facies in the Kope. This "Excello"-Waynesville Shale Member boundary is interpreted as the end of the second transgressive-regressive cycle and the beginning of the third, which culminated in deposition of the sediments of the Whitewater and Saluda Formations, which are exposed in the outcrop at Garr Hill (IN-FR-0003).

Beyond the data provided in the overall faunal chart (fig. 10-3), the faunas of the Bon Well Hill section, especially the mollusks, were discussed by Frey (*in* Hay and others, 1981); most of the next several paragraphs is taken from his discussion:

The well-known Upper Ordovician fauna characteristic of

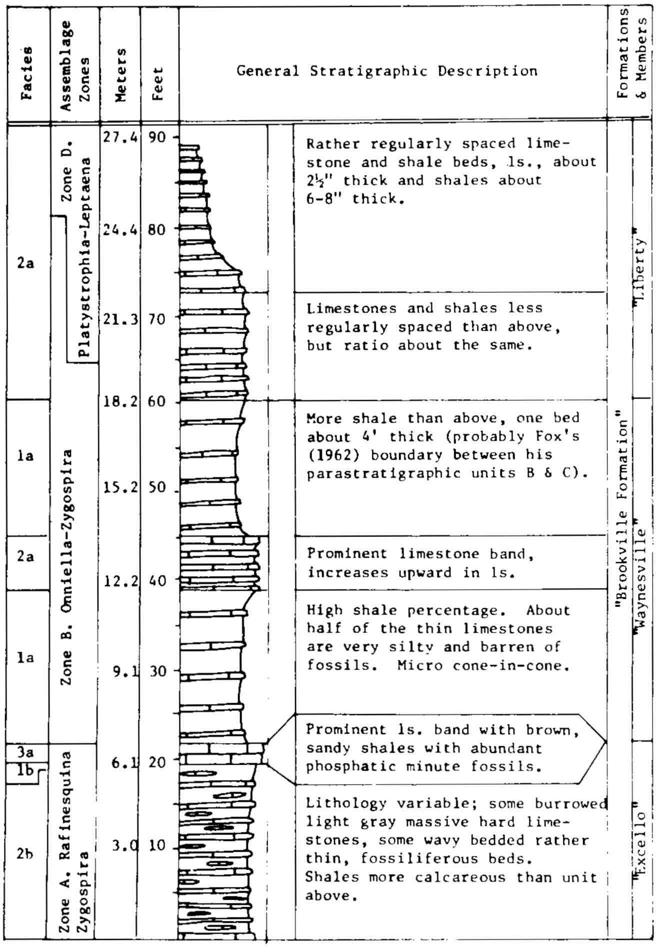

FIGURE 10-3.—Stratigraphic section exposed at Bon Well Hill (from Hay and others, 1981, p. 82, fig. 7; with permission).

the classical Cincinnati area is best known for its well-preserved articulate brachiopods and trepostome ectoprocts. A closer examination of the Upper Ordovician section exposed at Bon Well Hill, however, indicates that some lithologic units, especially the more argillaceous limestones and claystones, have faunas dominated by mollusks, particularly pelecypods. Some of these argillaceous strata have large, diverse faunas of mollusks, trilobites, and echinoderms. One such unit is the "trilobite shale," which is located in the Waynesville Shale Member of the "Brookville formation," exposed at the 15-meter (49-ft) interval at this locality (fig. 10-3). Fifty species of invertebrates have been collected and identified from this 1.5-meter-thick (5-ft-thick) claystone unit; 13 of these are pelecypods. Pelecypods dominated brachiopods in Paleozoic shallow-marine environments where local conditions were such that mobility was an asset and nutrient supply was plentiful. The "trilobite shale" was probably deposited under such conditions, as articulate brachiopods and trepostomes are uncommon, whereas the endobyssate suspension-feeding pelecypods *Ambonychia suberecta* (Ulrich), *Corallidomus concentricus* (Hall and Whitfield), and *Pholadomorpha pholadiformis* (Hall) are abundant (densities up to 160 individuals/m^2) and reach large size (up to 75 mm in length). Brachiopods become plentiful only at the very top of the shale where bedding planes are covered with valves of the ubiquitous "pioneer" genera *Rafinesquina* and *Onniella*.

In contrast to the richness of the fauna of the "trilobite shale," the lowermost shales of the Waynesville Shale Member have a sparse fauna of linguloid brachiopods, small paleotaxodont pelecypods, and occasional trilobites. This portion of the Waynesville Shale Member is thought to represent very shallow water conditions and a more stressful environment than that of the "trilobite shale" unit. Other molluscan-rich assemblages include a 2-meter (6.6-ft) band of rubbly calcareous mudstone near the top of the "Excello member," which is exposed at the lower (southwest) end of the Bon Well Hill exposure. This unit contains specimens of the ambonychiid pelecypods *Ambonychia alata* Meek and *Anomalodonta gigantea* S. A. Miller plus the cylindrical pelecypod *Orthodesma recta* Hall and Whitfield, which is often preserved in its presumed life position, with the posterior end of the shell directed up, perpendicular to bedding planes. The platycerid gastropod *Cyclonema humerosum* Ulrich is also abundant in this unit.

The strata at the base of the Bon Well Hill section would be referred to the upper Arnheim or Oregonia of the traditional Cincinnatian units.

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Addresses of authors: Helen B. Hay, deceased, formerly Geology Department, Earlham College, Richmond, IN 47374; and Roger J. Cuffey, Department of Geosciences (Deike Bldg.), Pennsylvania State University, University Park, PA 16802.

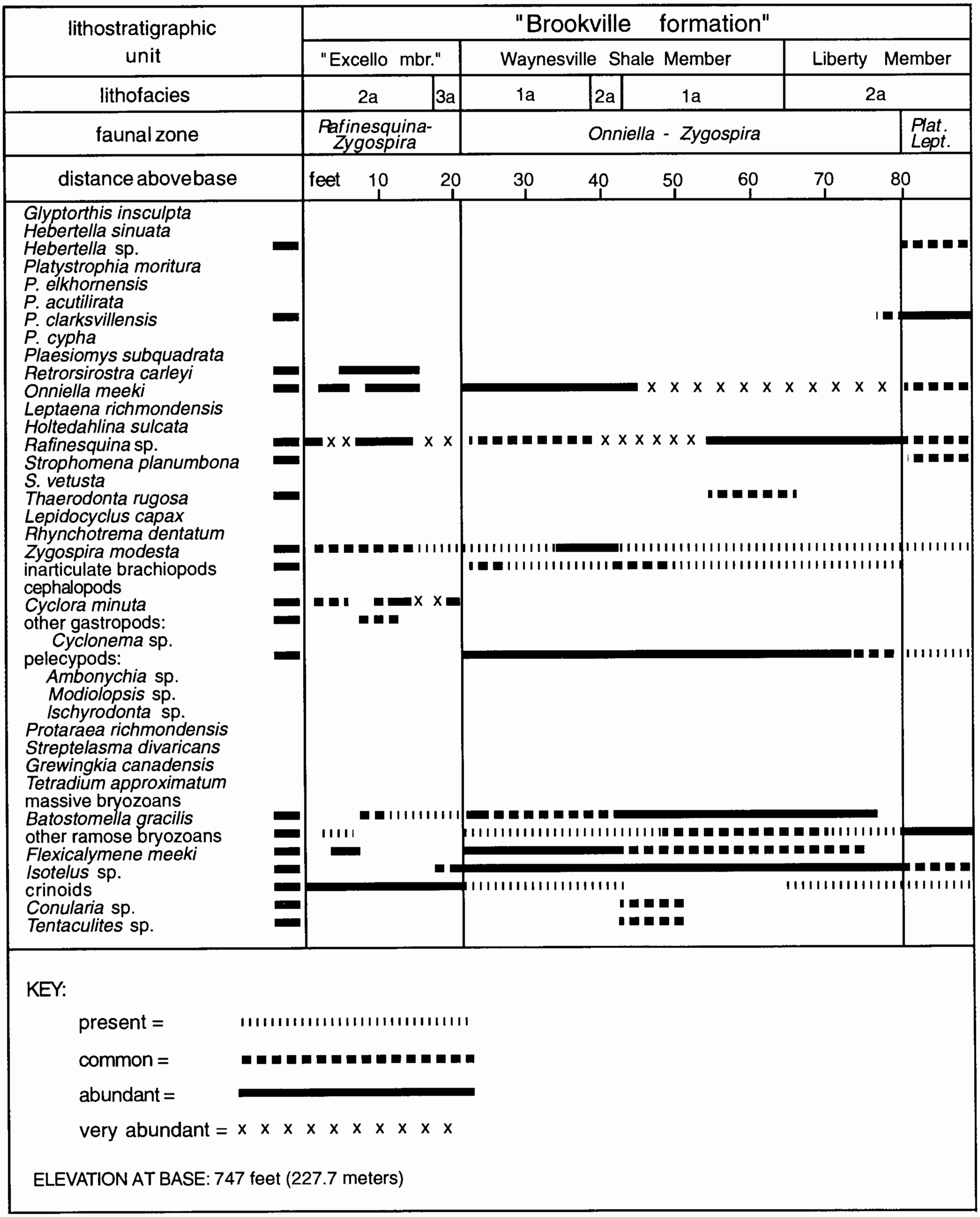

FIGURE 10-4.—Fauna of the Bon Well Hill section (modified from Hay and others, 1981, p. 83, fig. 8). Note that *Lepidocyclus capax* (Conrad, 1842) was assigned to the genus *Hiscobeccus* by Amsden in 1983.

Principal diagnostic characteristics of lithofacies		
Group 1 >70% shale	1a	Well-bedded, mostly thin limestones and medium to thick, fissile to blocky shales. Includes massive units of 100% shale. Low-diversity fauna.
	1b	Rubbly, shaly, nodular limestones; medium to thick shales with limy stringers and layers of fossils in shale matrix. May have some well-bedded limestones as in 1a. Low-diversity fauna. Most easily seen in cores.
Group 2 55-70% shale	2a	Like 1a except has high diversity of fauna. Intermediate in shale percentage between 1a and 3a.
	2b	Well-bedded limestones, rubbly nodular limestones, and limy shales. Allochems tend to be more finely broken than 2a. High-diversity fauna. Intermediate between 3a and 3c.
Group 3 <55% shale	3a	Well-bedded, thin to medium limestones and thin to medium, fissile to blocky shales. High-diversity fauna.
	3b	Well-bedded, thin to medium limestones with or without rubbly or nodular shales. High-diversity fauna. Intermediate between 3a and 3c.
	3c	Thin-bedded, rubbly weathering, argillaceous limestones, very thin limy shales. High-diversity fauna.
	3d	Limestones and shales as in 3a except >20% of limestones are fine-grained laminated burrowed, barren of large fossils; trails on tops. Grade to siltstones.
Group 4 Miscellaneous	4a	High-angle cross-bedded calcarenites, bimodal dip. Little or no shale.
	4b	Granule-size fossils in thick to massive beds; little or no shale. May be like 4a if seen in similar outcrops.
	4c	Massive *Loxoplocus* limestone bed. Marble Hill Bed.
	4d	Bioturbated light-gray limestone with low-diversity fauna of ostracodes, algae, snails, and *Tetradium*. Related to Saluda facies complex.

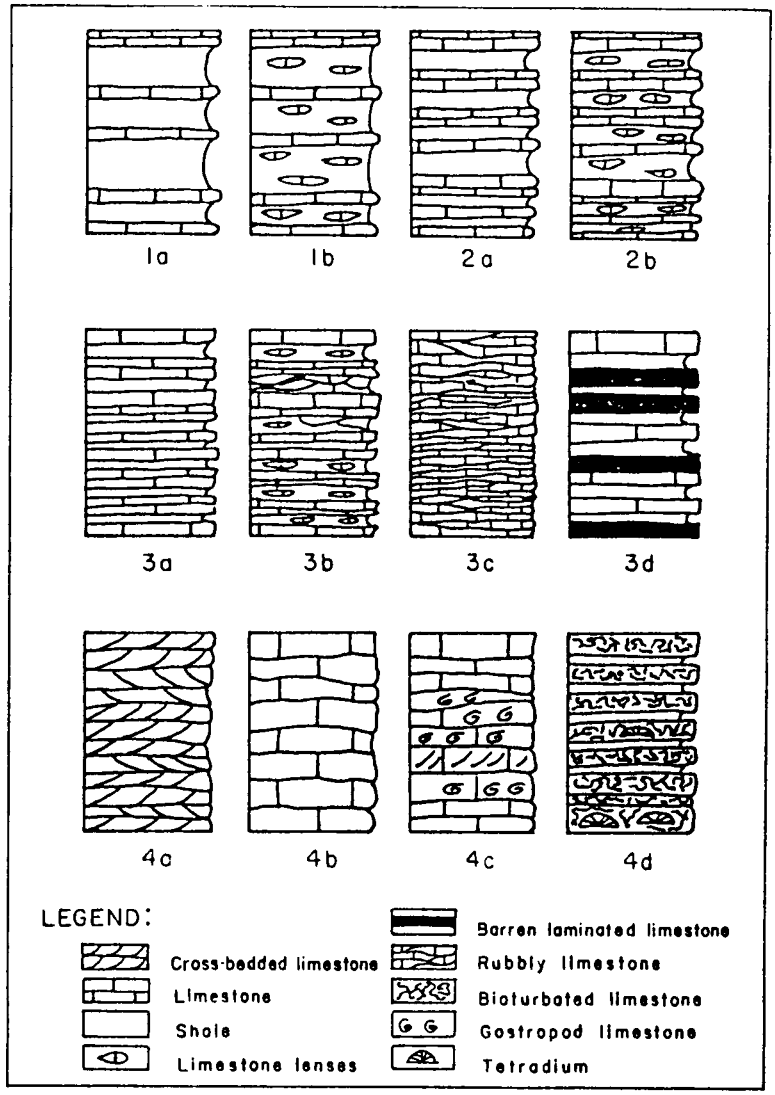

FIGURE 10-5.—Lithofacies characteristics (see Hay, paper 17 in this volume).

11. LIBERTY, LOWER AND UPPER WHITEWATER, AND SALUDA STRATA AT GARR HILL/BROOKVILLE NORTH (UPPER ORDOVICIAN, SOUTHEASTERN INDIANA)

by
Helen B. Hay and Roger J. Cuffey

SIGNIFICANCE

The Garr Hill road cut (fig. 11-1) exposes the upper part of the Brookville composite section (fig. 11-2), which is discussed and correlated in Hay and Cuffey's discussion on the Brookville Dam spillway locality (paper 8 in this volume; see also Hay, 1977, p. I-5 to I-6, and Hay and others, 1981). Particularly noteworthy here are the abundant, diverse fossils at the base of the section and the *Tetradium* coral zone and Saluda Formation near the top.

LOCATION

The Garr Hill/Brookville North locality (IN-FR-0003) is the long road cut on both sides of Indiana Route 101, 6.0-6.4 miles (9.6-10.2 km) northeast of the junction of U.S. Route 52 and Indiana Route 101 at the north edge of Brookville, Franklin County, Indiana (fig. 11-1). The road cut is 0.8-1.2 miles (1.3-1.9 km) south from the crossroads at the office of the Mounds State Recreation Area, which is about 10 miles (16 km) south of Liberty, Indiana. Elevation of the base of the measured section is 900 ft (274.3 meters). The road cut occupies the E$\frac{1}{2}$SE$\frac{1}{4}$NE$\frac{1}{4}$ and E$\frac{1}{2}$NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 35, T. 10 N., R. 2 W., Whitcomb, Indiana, 7.5-minute quadrangle, at 39°29'11" to 39°29'29"N, 84°56'58"W (4372556-4373108 m N, 676410 m E, UTM zone 16). The name "Garr Hill" appears on the topographic map about a mile southwest of the road cut, but applies to the entire complex of hills in the surrounding vicinity.

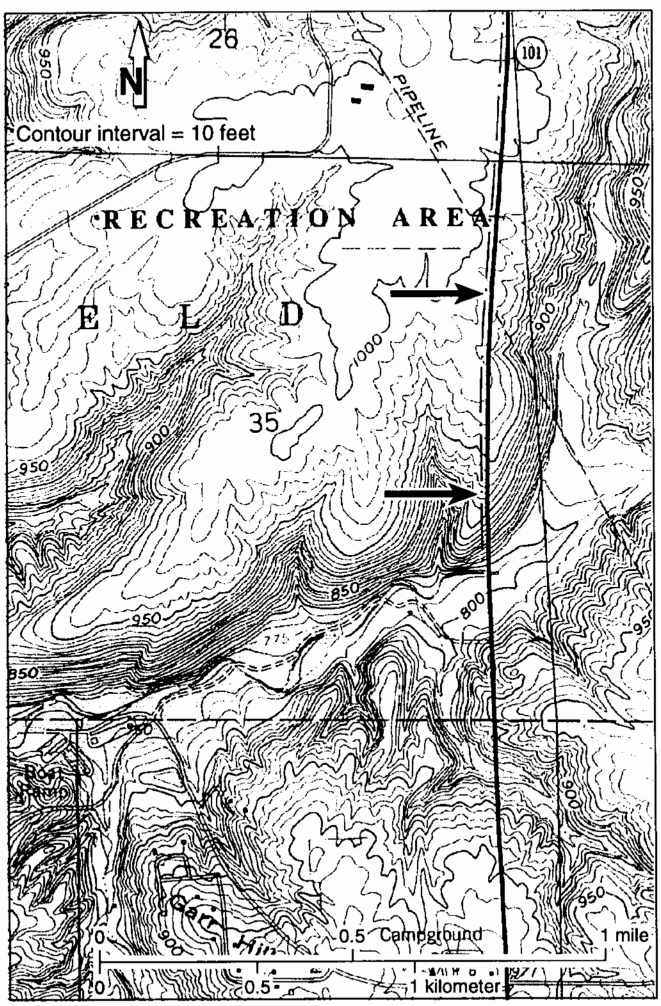

FIGURE 11-1.—Location of the Garr Hill/Brookville North road cut (extent marked by arrows). Whitcomb, Indiana, 7.5-minute quadrangle.

STRATIGRAPHY AND PALEONTOLOGY

Hay (1977, p. I-18 to I-22) presented a preliminary version of the Garr Hill/Brookville North section and later updated it (Hay and others, 1981, p. 80, 84-86). Much of the following discussion is taken from Hay and others (1981).

The Garr Hill section includes, from bottom to top, the Liberty Member of the "Brookville formation," the lower part of the Whitewater Formation, a thin, coral-bearing Saluda unit, and the basal beds of the upper part of the Whitewater Formation (fig. 11-3). Local ranges of important fossil species are given in figure 11-4. Hay (1981), Hay and others (1981), and Hay (paper 17 in this volume) discuss the lithofacies identified here (fig. 11-5) and the stratigraphic classification applied to these rocks.

The base of the road cut exposes fossiliferous gray limestone and blue- to light-gray shale of the Liberty Member of "Brookville formation." The Liberty is overlain by lenticular to rubbly limestones and shales of the Whitewater Formation. A relatively thin interval of the Saluda Formation, consisting of calcisiltite strata including zones of tabulate corals (*Tetradium*) is intercalated in the Whitewater strata.

This outcrop is of interest not only because it exposes several different facies and faunal assemblages (figs. 11-3, 11-4), but also because it shows a stratigraphic sequence of facies interpreted as the regressive phase of the third transgressive-regressive cycle in the Cincinnatian. The transgressive phase of the third cycle probably began with deposition of the muds of the Waynesville Shale Member (Bon Well Hill; see paper 10 in this volume), and the peak of the transgression is represented by facies 2a at the base of this locality, Garr Hill. There is a gap of 9 meters (30 ft) between these two outcrops, based on comparison with the continuous exposure at South Gate Hill (see paper 12 in this volume).

Facies 2a at the base of the Garr Hill/Brookville North section has an abundant and extremely diverse fauna. The abundant and well-preserved brachiopods represent more genera than occur together at any other stratigraphic position in the Cincinnatian of this area. Horn corals first appear in Indiana and Ohio at this level; bryozoans, trilobites, echinoderms, and mollusks are also abundant. This faunal assemblage suggests deposition on a stable open shelf, in comparison to the less stable, more rigorous conditions indicated by the lower diversity and the lack of fossils near the base of the underlying Waynesville Shale Member. The abraded fossils, some jumbled together in coquinalike beds,

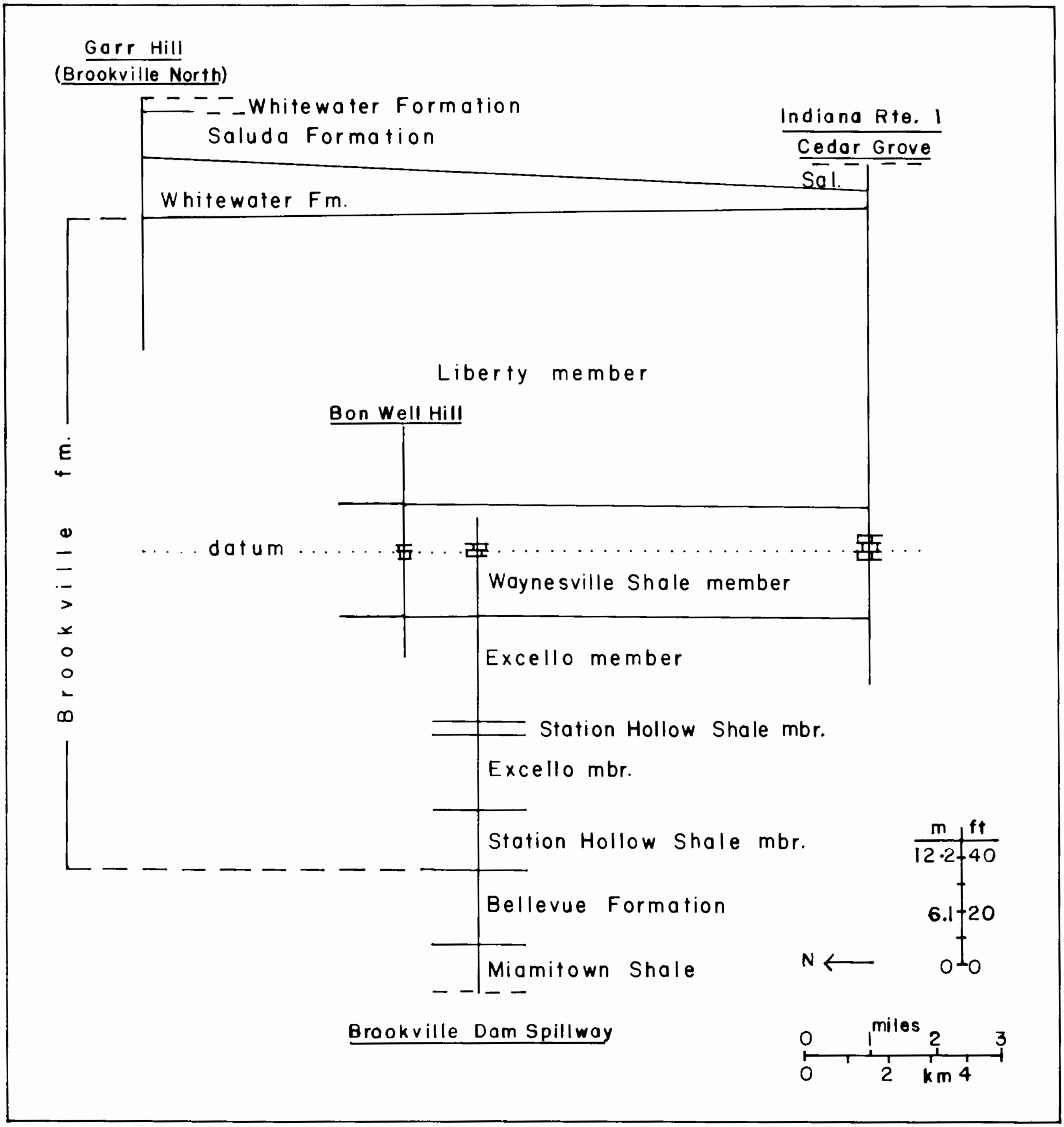

FIGURE 11-2.—Correlation of the four localities that collectively make up the Brookville composite section: Garr Hill/Brookville North (IN-FR-0003), Bon Well Hill (IN-FR-0001), Brookville Dam Spillway (IN-FR-0002), and Indiana Route 1/South Gate Hill, labeled as Cedar Grove (IN-FR-0005).

indicate periodic high-energy conditions, which would be expected on a shallow open shelf.

The increase in limestone percentage upward in this outcrop, from facies 2a to 3a to 3d, is interpreted as an indication of shoaling, so that sediments of the later two facies were deposited at or near wave base. The contact between the well-bedded rocks of the Liberty Member and the rubbly rock (facies 3c) of the Whitewater Formation is gradational here, as it is at many other localities. The gradational strata, assigned to facies 3b, are included in the Whitewater Formation. The rubbly rock of facies 3c is well exposed at the top of the outcrop, where it is somewhat weathered.

The *Tetradium* coral layer and associated facies 4d of the Saluda Formation is well exposed in this outcrop. Hatfield (1968) interpreted the massive *Tetradium* colonies as serving the function of a wave baffle marginal to a shallow la-

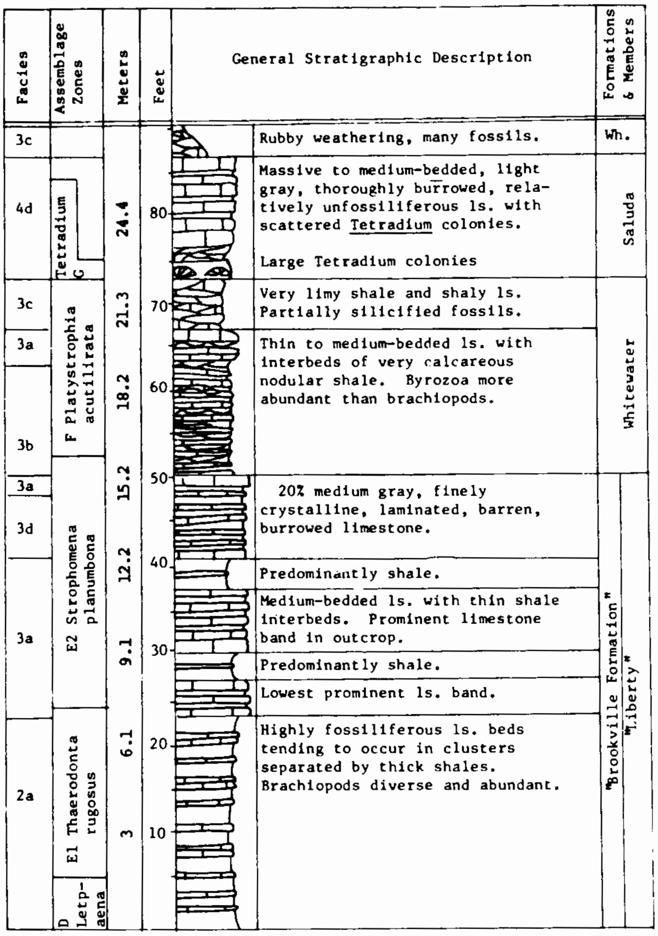

FIGURE 11-3.—Stratigraphic section at Garr Hill/Brookville North (from Hay and others, 1981, p. 84, fig. 9; with permission).

goonal setting that produced the silty dolomites that are characteristic of the Saluda Formation farther south in Indiana. At this locality, however, only the coral zone and the burrowed micritic limestones of facies 4d occur. These burrowed limestones of facies 4d have an unusual fauna dominated by algae and small mollusks and probably formed around the edge of the Saluda lagoon just inside the *Tetradium* wave-baffle zone. The Saluda sediments bearing mud cracks undoubtedly were deposited in very shallow water and were intermittently exposed to the atmosphere.

Facies 3c, the characteristic facies of the Whitewater Formation, also represents very shallow conditions on the basis of its stratigraphic association with the Saluda and its unique lithologic characteristics. Facies 3c may be envisioned as representing the relatively quiet interior of a shallow platform. Toward the margin of the platform, sediments of facies 3b were deposited, and at the platform margin, facies 3a. In slightly deeper water the shalier sediment of facies 2a accumulated. This scenario is supported by analysis of facies sequences, characteristics of individual facies, and the geometry of these facies bodies throughout the region. Superposition of these facies, as in this outcrop, indicates regression.

Correlation of the Garr Hill/Brookville North locality with the Richmond composite section to the north is discussed in paper 15 in this volume.

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Addresses of authors: Helen B. Hay, deceased, formerly Geology Department, Earlham College, Richmond, IN 47374; and Roger J. Cuffey, Department of Geosciences (Deike Bldg.), Pennsylvania State University, University Park, PA 16802.

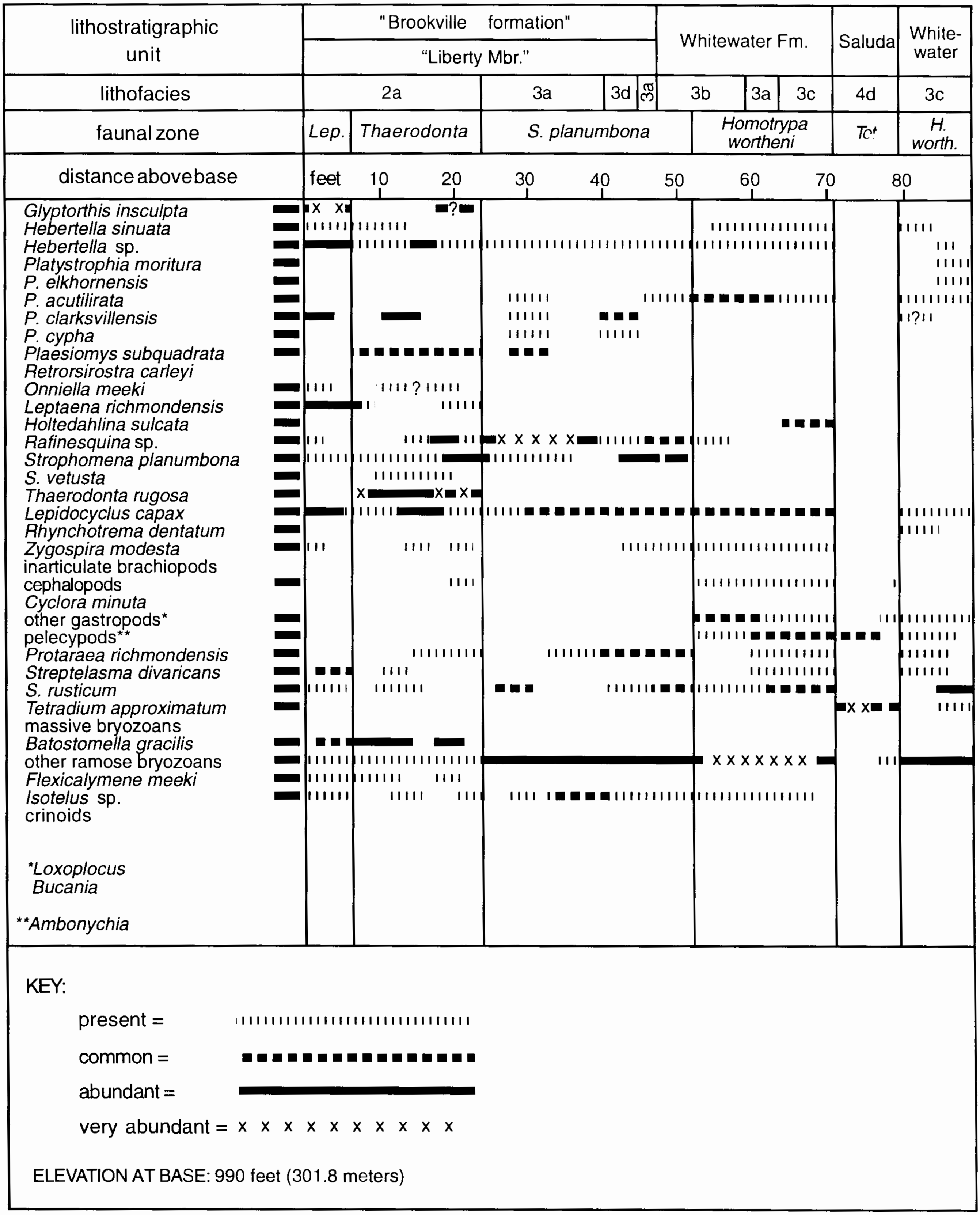

FIGURE 11-4.—Fauna of the Garr Hill/Brookville North section (from Hay and others, 1981, p. 85, fig. 10; with permission). *Lep.* = *Leptaena*; *S. planumbona* = *Strophomena planumbona*; Tet. = *Tetradium*. Note that *Lepidocyclus capax* (Conrad, 1842) was assigned to the genus *Hiscobeccus* by Amsden in 1983.

Principal diagnostic characteristics of lithofacies		
Group 1 >70% shale	1a	Well-bedded, mostly thin limestones and medium to thick, fissile to blocky shales. Includes massive units of 100% shale. Low-diversity fauna.
	1b	Rubbly, shaly, nodular limestones; medium to thick shales with limy stringers and layers of fossils in shale matrix. May have some well-bedded limestones as in 1a. Low-diversity fauna. Most easily seen in cores.
Group 2 55-70% shale	2a	Like 1a except has high diversity of fauna. Intermediate in shale percentage between 1a and 3a.
	2b	Well-bedded limestones, rubbly nodular limestones, and limy shales. Allochems tend to be more finely broken than 2a. High-diversity fauna. Intermediate between 3a and 3c.
Group 3 <55% shale	3a	Well-bedded, thin to medium limestones and thin to medium, fissile to blocky shales. High-diversity fauna.
	3b	Well-bedded, thin to medium limestones with or without rubbly or nodular shales. High-diversity fauna. Intermediate between 3a and 3c.
	3c	Thin-bedded, rubbly weathering, argillaceous limestones, very thin limy shales. High-diversity fauna.
	3d	Limestones and shales as in 3a except >20% of limestones are fine-grained laminated burrowed, barren of large fossils; trails on tops. Grade to siltstones.
Group 4 Miscellaneous	4a	High-angle cross-bedded calcarenites, bimodal dip. Little or no shale.
	4b	Granule-size fossils in thick to massive beds; little or no shale. May be like 4a if seen in similar outcrops.
	4c	Massive *Loxoplocus* limestone bed. Marble Hill Bed.
	4d	Bioturbated light-gray limestone with low-diversity fauna of ostracodes, algae, snails, and *Tetradium*. Related to Saluda facies complex.

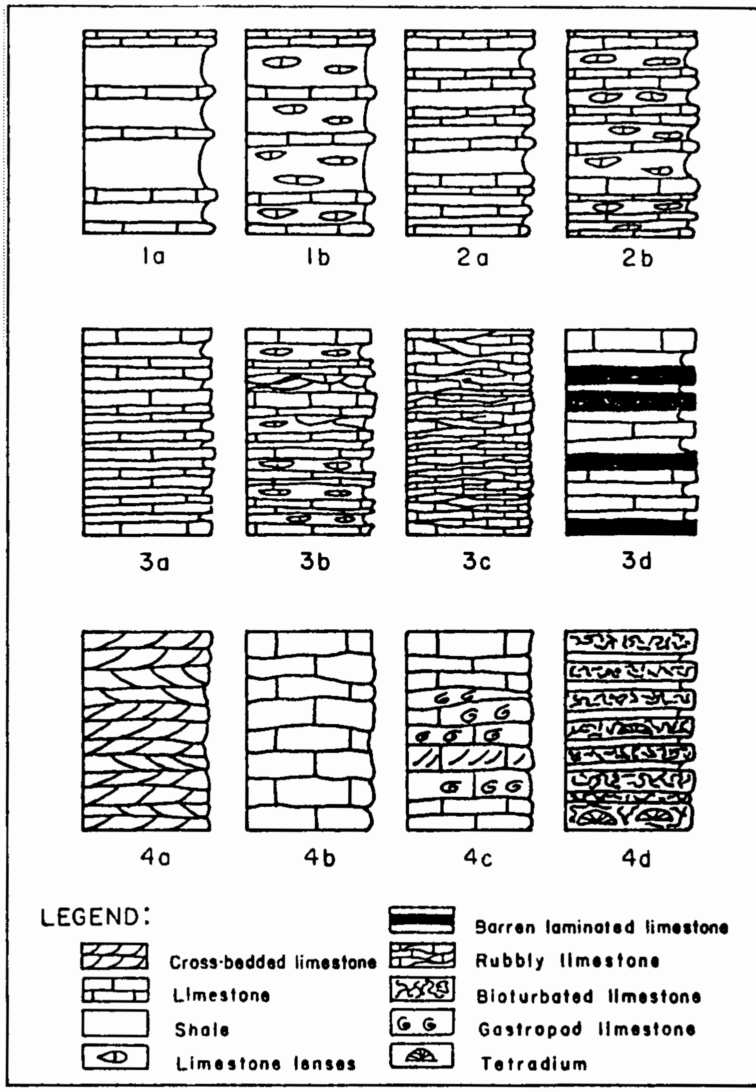

FIGURE 11-5.—Lithofacies characteristics (see Hay, paper 17 in this volume).

12. "EXCELLO" (ARNHEIM) TO BASAL SALUDA STRATA ON INDIANA ROUTE 1 AT SOUTH GATE HILL (UPPER ORDOVICIAN, SOUTHEASTERN INDIANA)

by
Helen B. Hay, Brian Kirchner, and Roger J. Cuffey

SIGNIFICANCE

The spectacular road cuts on the long slope down South Gate Hill (fig. 12-1) expose 61 meters (200 ft) of section, including much of the Richmondian Stage in southeastern Indiana. When added to the exposure at the Brookville Dam Spillway (IN-FR-0002), a total stratigraphic interval of 98 meters (310 ft) is exposed within a distance of about 6 miles, extending from the Maysvillian Miamitown Shale at the base to the Richmondian Saluda Formation at the top (fig. 12-2). Included in this interval are the Bellevue Formation and all of the "Brookville formation." Also important is the geographic location of these outcrops north and west along the Cincinnati Arch; the Brookville Dam spillway provides the northernmost known exposure of Maysvillian rocks in Indiana. Therefore, the four outcrops in the vicinity of Brookville—the Brookville Dam spillway (IN-FR-0002), Bon Well Hill (IN-FR-0001), Garr Hill (IN-FR-0003), and this locality, South Gate Hill—are significant for regional correlation with cores and other outcrops in Indiana and Ohio. The other Brookville localities are each described in other papers in this volume (8, 10, and 11, respectively). This locality also correlates with the Madison/U.S. Route 421 sections (IN-JE-0001, IN-JE-0002, and IN-JE-0003) described in paper 6 in this volume.

LOCATION

South Gate Hill (IN-FR-0005), also called the Indiana Route 1 or the Cedar Grove locality, consists of road cuts on both sides of Indiana Route 1, 1.0-1.5 miles (1.6-2.4 km) north of the crossroads at the village of South Gate and 1.9-2.4 miles (3.0-3.8 km) south of the junction with U.S. Route 52 west of Cedar Grove, Franklin County, Indiana (fig. 12-1). These cuts are in the W$^1/_2$W$^1/_2$SE$^1/_4$ sec. 23, T. 8 N., R. 2 W., Cedar Grove, Indiana, 7.5-minute quadrangle, at 39°20'08" to 39°20'30"N and 84°57'20 to 84°57'24"W (4355853-4356469 m N, 676098-676194 m E, UTM zone 16). Elevation of the base of this section is about 750 ft (228.6 meters). The highway has recently been greatly improved, but its roadbed apparently remains in almost the same position as on the published topographic map. Recently, signs forbidding digging here have appeared, and so appropriate caution or conservation should be observed.

STRATIGRAPHIC DESCRIPTION

Exposed in the South Gate Hill road cuts are strata of the Saluda Formation, the lower part of the Whitewater Formation, and the "Brookville formation"; the "Brookville" includes the Liberty Member, the Waynesville Shale Member, and the "Excello member" (fig. 12-3). Initial field descriptions were reported by Kirchner (1991); they are updated in this present paper, although recording of the local ranges of fossils is not yet finalized and, hence, such are not included. Lithofacies recognized here (fig. 12-4) are discussed more fully by Hay (1981), Hay and others (1981), and Hay (paper 17 in this volume).

SALUDA FORMATION

At this location 9+ ft (2.7+ meters) of Saluda is exposed. The facies is 4d and consistgs of thoroughly burrowed, micritic, light-gray limestone containing *Tetradium* in some beds. There is a large *Tetradium* colony in float at the top of the section. No thin sections are available from this location; thin sections from Garr Hill show that the fossils present are algae with structure preserved, ostracodes, and small snails; very few are normal-marine fossils of the Cincinnatian. No dolomite was found either at Garr Hill or South Gate Hill, although facies 4d is associated with Saluda dolomitic facies farther west and southwest, giving confidence to the assignment of this interval to the Saluda.

WHITEWATER FORMATION

At this locality 5 ft (1.5 meters) of the lower or sub-Saluda part of the Whitewater Formation is present. The rocks consist primarily of facies 3b—planar or rubbly limestones and limy shales; limestone is >50 percent. There are some beds of facies 4d (characteristic of the Saluda); thus, it possibly could be included in the Saluda. Overall, this unit is transitional between Whitewater and Saluda lithologies.

"BROOKVILLE FORMATION"

The informal name "Brookville formation" was proposed by Hay and others (1981, p. 76) for the rocks between the top of the Bellevue Limestone and the bottom of the Whitewater Formation. (It is not the same rock unit as the Brookville Clay of Pennsylvania nor the Brookville Terrane of Kansas.) The "Brookville formation," as used here, is the same as much of the upper part of the Dillsboro Formation, as recognized by the Indiana Geological Survey (Brown and Lineback, 1966; Gray, 1972; Hay, paper 17 in this volume). It likewise is equivalent to the Corryville through Liberty interval of Caster, Dalvé, and Pope (1955), and the Corryville Member of the Grant Lake Formation through the Liberty Formation of the Ohio Division of Geological Survey (Schumacher and others, 1991).

LIBERTY MEMBER

The Liberty Member here has 115 ft (35.1 meters) present. The section is described in five parts.

(1) The upper 35.5 ft (10.8 meters) is mostly facies 3a; <55 percent shale with planar limestones; a majority of the shales lack limy lenses, stringers, or nodules (not limy shales). Facies 3d at the top of the interval is like 3a except that >20 percent of the limestones are composed of sand- and silt-size allochems and are laminated and burrowed. Facies 3d also occurs within the Liberty at Garr Hill.

(2) The upper interval of facies 1a is 8 ft (2.4 meters) thick and is >70 percent shale; this unit is a marker unit in the outcrop (fig. 12-3, 150-foot level). Hay surmised that the top of this shale may be where the Ohio Geological Survey might put the contact between the Waynesville and the Liberty; if

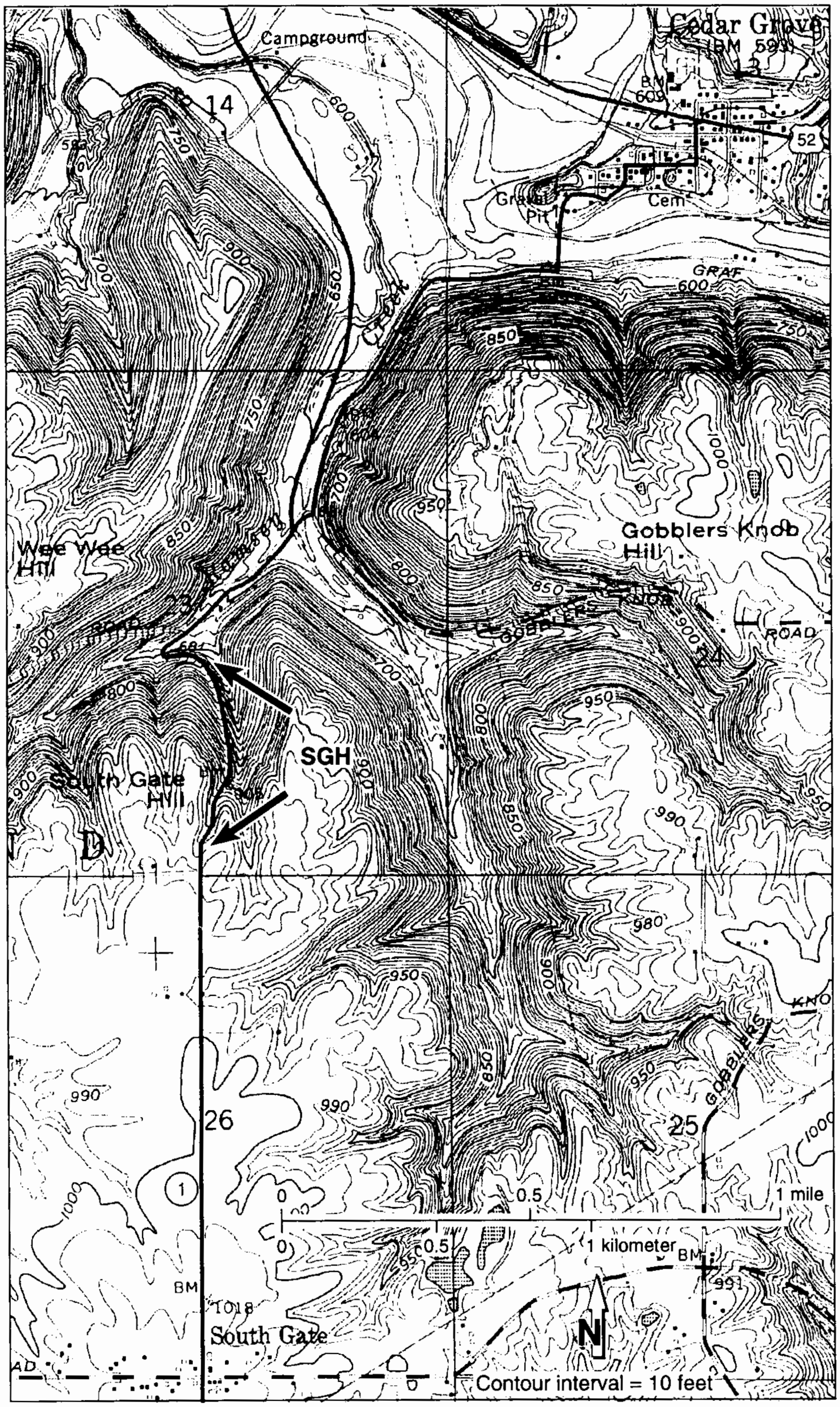

FIGURE 12-1.—Location of the South Gate Hill road cuts (**SGH**; arrows indicate extent of exposures) along Indiana Route 1. Cedar Grove, Indiana, 7.5-minute quadrangle.

this interpretation is correct, the Liberty at this locality would be 10.8 meters (35.5 ft) thick, rather than 35.1 meters (115 ft) as stated here, and the Waynesville would be 36.7 meters (120.5 ft) thick, rather than 12.5 meters (41.0 ft). For discussion of this suggested modification of the Waynesville-Liberty boundary, see Hay (paper 17 in this volume).

(3) Facies 2a is 20 ft (6.1 meters) thick and is like facies 3a above except that the shale percentage is 55-70 percent. The *Thaerodonta* peak zone is either within this interval or within the 3a zone just above the 150-foot level.

(4) Facies sequence 2b, 3b, 2b is 36.5 ft (11.1 meters) thick.

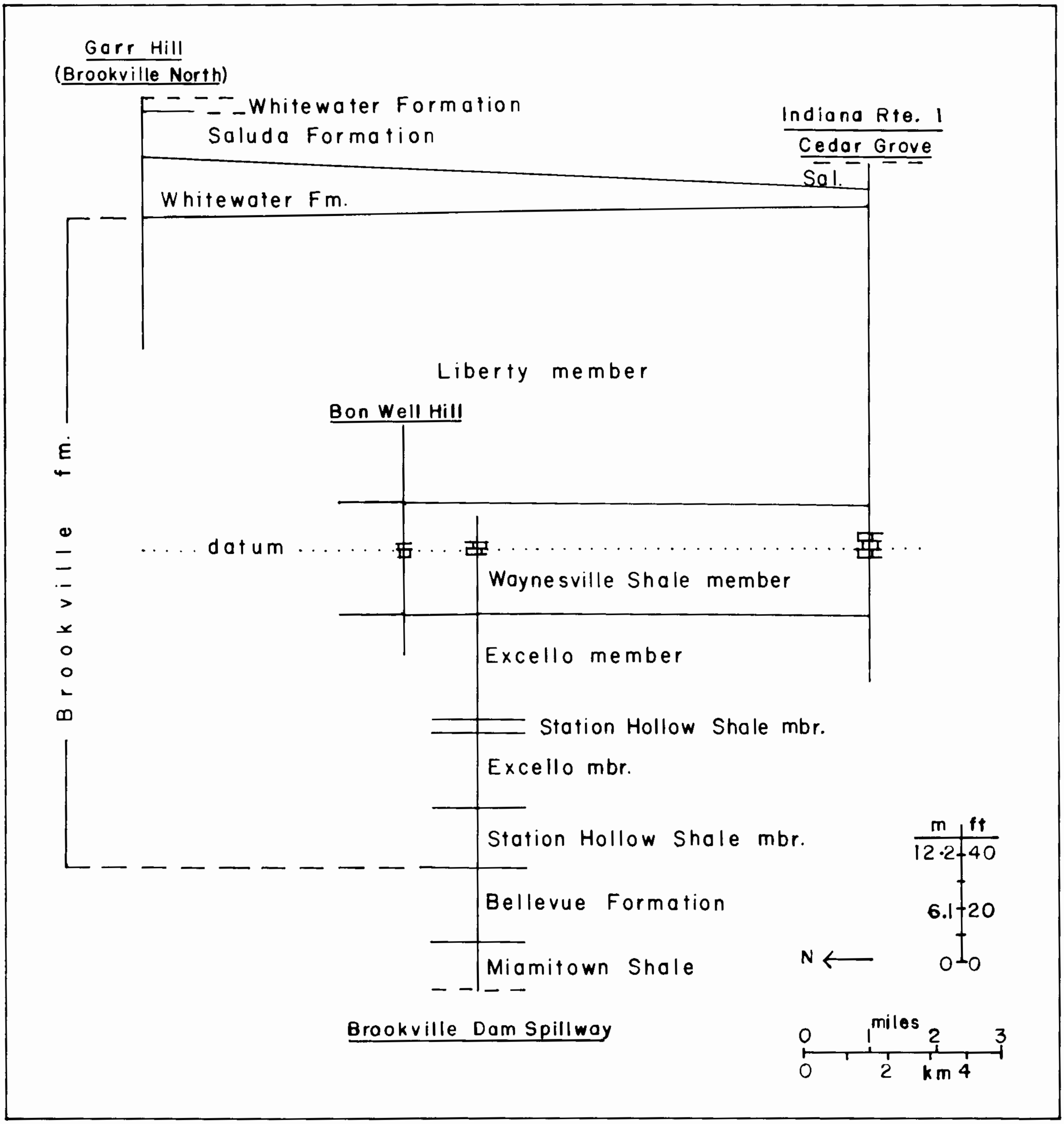

FIGURE 12-2.—Correlation of the South Gate Hill section (IN-FR-0005), here labeled Indiana Rte. 1 Cedar Grove, with the other three localities that collectively make up the Brookville composite section: Bon Well Hill (IN-FR-0001), Brookville Dam spillway (IN-FR-0002), and Garr Hill/Brookville North (IN-FR-0003).

Facies 2b is 55-70 percent shale with limy shales and planar or rubbly limestones; facies 3b is the same as 2b except that it contains <55 percent shale. Faunal diversity increases from the lower part of this interval upward. The *Glyptorthis* interval is tentatively located within the 3b unit, the 2b unit above it, or both; this interval correlates faunally with the base of the Garr Hill section.

(5) The lower interval of facies 2a is 14.5 ft (4.4 meters) thick and is the same as (3) above. The boundary between the Liberty and the Waynesville (at the base of the unit) is placed to include in the Liberty the strata in which the shale percentage is predominantly <70 percent. The shale per-

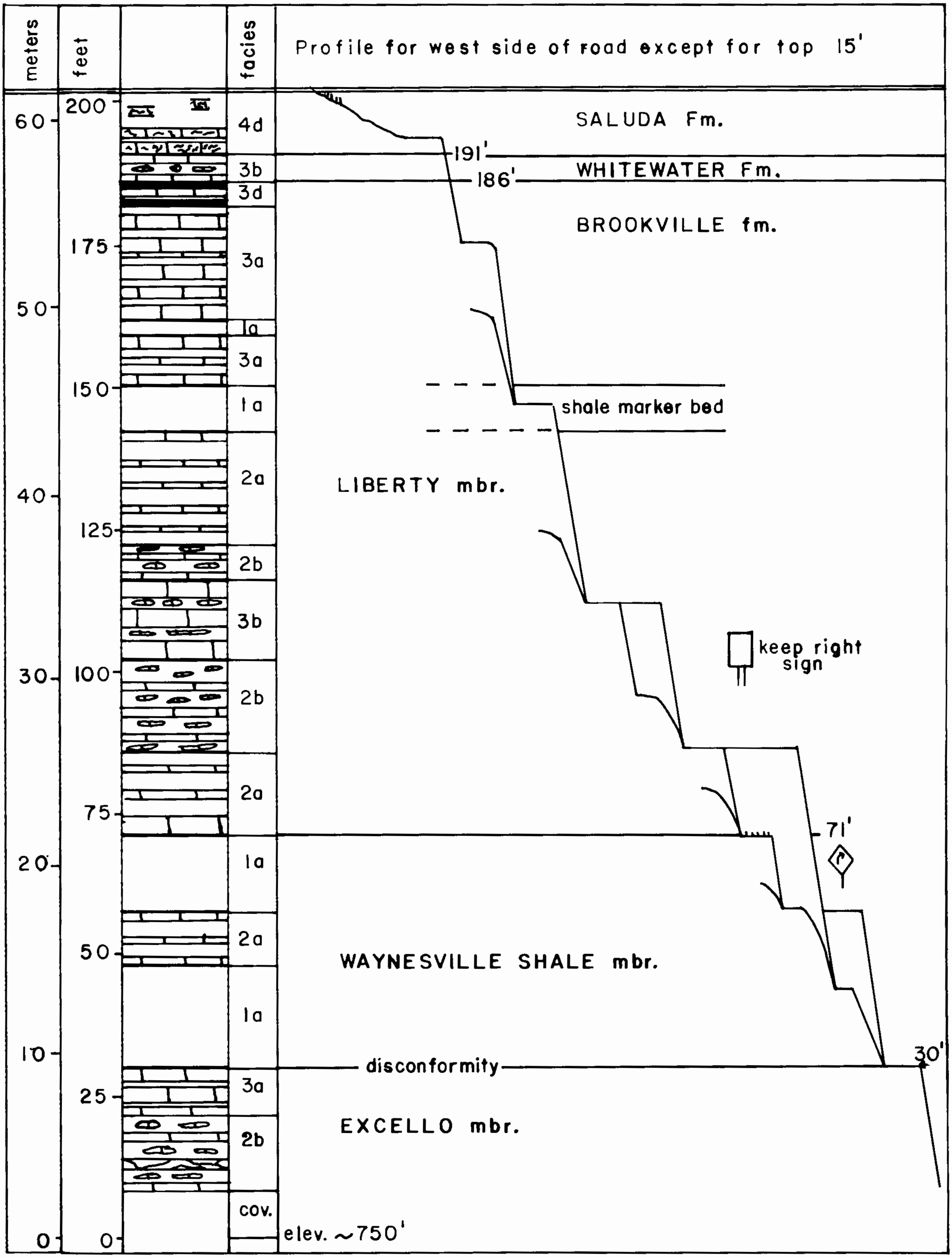

FIGURE 12-3.—Stratigraphic section exposed at South Gate Hill. Profile shows topographic benches, faces, and road signs along the west side of Indiana Route 1 as of late 1991. Although the position of the disconformity is placed above the interval of facies 3a, it is possible that the disconformity lies below this interval. See figure 12-4 for explanation of the lithologic patterns and facies.

Principal diagnostic characteristics of lithofacies	
Group 1 >70% shale	1a Well-bedded, mostly thin limestones and medium to thick, fissile to blocky shales. Includes massive units of 100% shale. Low-diversity fauna.
	1b Rubbly, shaly, nodular limestones; medium to thick shales with limy stringers and layers of fossils in shale matrix. May have some well-bedded limestones as in 1a. Low-diversity fauna. Most easily seen in cores.
Group 2 55-70% shale	2a Like 1a except has high diversity of fauna. Intermediate in shale percentage between 1a and 3a.
	2b Well-bedded limestones, rubbly nodular limestones, and limy shales. Allochems tend to be more finely broken than 2a. High-diversity fauna. Intermediate between 3a and 3c.
Group 3 <55% shale	3a Well-bedded, thin to medium limestones and thin to medium, fissile to blocky shales. High-diversity fauna.
	3b Well-bedded, thin to medium limestones with or without rubbly or nodular shales. High-diversity fauna. Intermediate between 3a and 3c.
	3c Thin-bedded, rubbly weathering, argillaceous limestones, very thin limy shales. High-diversity fauna.
	3d Limestones and shales as in 3a except >20% of limestones are fine-grained laminated burrowed, barren of large fossils; trails on tops. Grade to siltstones.
Group 4 Miscellaneous	4a High-angle cross-bedded calcarenites, bimodal dip. Little or no shale.
	4b Granule-size fossils in thick to massive beds; little or no shale. May be like 4a if seen in similar outcrops.
	4c Massive *Loxoplocus* limestone bed. Marble Hill Bed.
	4d Bioturbated light-gray limestone with low-diversity fauna of ostracodes, algae, snails, and *Tetradium*. Related to Saluda facies complex.

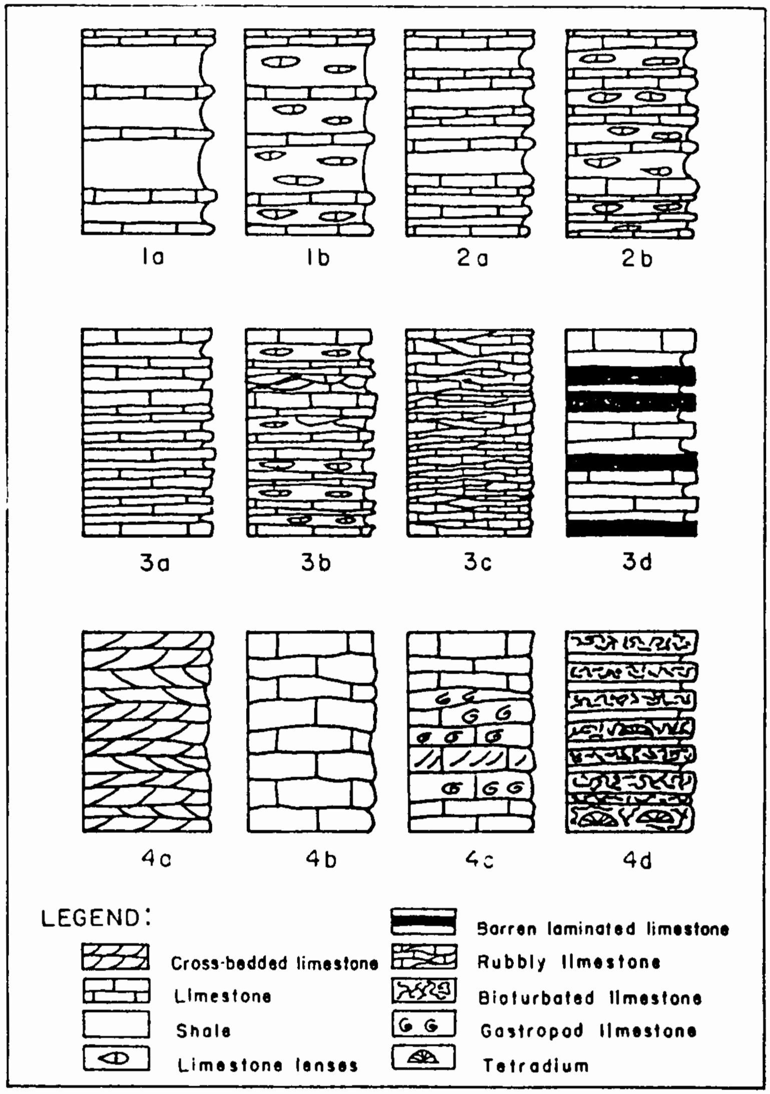

FIGURE 12-4.—Lithofacies characteristics (see Hay, paper 17 in this volume).

centage decreases upward to <55 percent in the upper part of the Liberty, as noted above.

WAYNESVILLE SHALE MEMBER

At this locality 41 ft (12.5 meters) of the Waynesville is present, consisting of mostly facies 1a (>70 percent shale), except for 9 ft (2.7 meters) of facies 2a in the middle. The shales are not limy and the limestones are planar rather than rubbly. The lowest part of the member, just above the top of the "Excello member," is nearly barren of fossils; indurated beds are siltstones rather than fossiliferous limestones. Fossil content increases upward; the brachiopod fauna is dominated by *Onniella* and *Rafinesquina*. The Waynesville/"Excello" boundary is interpreted to be a disconformity (Hay, 1981; Hay and others, 1981; Hay, paper 17 in this volume).

"Excello member"

At this locality, 22+ ft (6.7+ meters) of "Excello" (informal name) is exposed; it is described below in two parts. The portion of the "Excello" exposed here is the upper part of the Arnheim of Ohio usage (Schumacher and others, 1991). (Note that this is not the Excello Shale of Oklahoma.)

(1) Facies 3a is 8.5 ft (2.6 meters) thick and is <55 percent shale. Limestones are rather well-sorted calcarenites separated by brown shales with phosphatized steinkerns of small brachiopods, mollusks, and other fossils, which give these beds a sandy texture compared to most Cincinnatian gray shales. It is not certain whether this unit of facies 3a is just above or just below the disconformity.

(2) Facies 2b is 13.5+ ft (4.1+ meters) thick and is 55-70 percent shale. Shales are limy, and limestones are rubbly or planar. The limestones tend to be lighter gray than those higher in the section and contain a large fraction of sand-size allochems, including many crinoid ossicles.

PALEOENVIRONMENTAL INTERPRETATION

This facies sequence and the characteristics of the superimposed facies suggest an interpretation of changing environments through time that can be summarized as follows: (1) Regression, or at least a very shallow water environment, existed at the time the "Excello" sediments were deposited, with emergence producing a disconformity between them and the Waynesville Shale Member. Facies 3a at the top of the "Excello" may represent a beach in the regressive phase or the basal unit of the Waynesville transgression; in the latter case, this unit should be included in the Waynesville rather than in the "Excello." (2) The scarcity of fossils in the lowest part of the Waynesville followed upward by an increase in fossil abundance and diversity represents a transgressive phase that probably culminated in facies 2a in the Liberty at water depth below but near storm wave base. Therefore, the environment in which the sediments of the Waynesville Shale Member were deposited is best interpreted as very shallow water rather than relatively deep water. (3) Following the peak of the transgression in the basal facies 2a of the Liberty, there may have been a period of slight shoaling that resulted in deposition of the facies 2b-3b sequence, followed by a renewed minor transgression marked by the symmetrical overlying sequence of 2b-2a. In other words, the upward facies sequences of 2a, 2b, 3b, 2b, 2a probably represents a minor regressive phase followed by a minor transgressive phase. (4) The increase in limestone relative to shale (facies of group 3) near the top of the Liberty suggests a final shoaling phase that culminated in the environment responsible for the Saluda facies, 4d, which was probably deposited in extremely shallow water of somewhat higher than normal salinity, based on its association with dolomite and *Tetradium* at other localities (Hatfield, 1968; Hay, paper 17 in this volume). The depositional environments of the Saluda and the "Excello"/ Waynesville disconformity are two of the significant anchors to which this interpretation is tied.

The changes in water depth described here are probably only slight; all of these sediments indicate depositional environments above or, more commonly, not far below, storm wave base. The role of storms in final deposition of the carbonate sediments was probably very significant. Although extended discussion and justification for these interpretations is not feasible here, it is available elsewhere (Hay, 1981; paper 17 in this volume).

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Addresses of authors: Helen B. Hay, deceased, and Brian Kirchner, formerly Geology Department, Earlham College, Richmond, IN 47374; and Roger J. Cuffey, Department of Geosciences (Deike Bldg.), Pennsylvania State University, University Park, PA 16802.

13. UPPER ARNHEIM THROUGH LOWER WHITEWATER STRATA AT CAESAR CREEK LAKE (UPPER ORDOVICIAN, SOUTHWESTERN OHIO)

by

Gregory A. Schumacher, Douglas L. Shrake, E. Mac Swinford, Lynn A. Rockwell, and Roger J. Cuffey

SIGNIFICANCE

Exposures in the emergency spillway and below the dam of Caesar Creek Lake permit close examination of the abundantly fossiliferous, later Cincinnatian strata of the northeastern side of the Cincinnati Arch. These exposures can be profitably compared to those on the northwestern/western side of the arch (see papers in this volume on localities near Richmond, Brookville, and Madison, Indiana), as well as farther southward. Moreover, although the entire type-Cincinnatian is rightly regarded as fossiliferous, the strata in the Caesar Creek spillway are exceptionally so, to the point that the State of Ohio and the U.S. Army Corps of Engineers have taken the unusual step of permitting fossil collecting within this state park.

LOCATION

The Caesar Creek emergency spillway and dam are located about 3 miles (5 km) southeast of Waynesville, Warren County, Ohio (figs. 13-1, 13-2). They are situated at the southwestern end of Caesar Creek Lake/Reservoir, constructed and maintained by the U.S. Army Corps of Engineers. Caesar Creek State Park surrounds the lake.

From the junction of U.S. Route 42 and Ohio Route 73 at the south corner of Waynesville, proceed 1.1 miles (1.7 km) southeast on Route 73, turn south (at the Corps of Engineers sign) on Clarksville Road, and drive 3.2 miles (5.1 km) to the parking area in the middle of the spillway (fig. 13-2). En route, 2.3 miles (3.7 km) from Route 73, the Caesar Creek Visitors Center lies 0.2 mile (0.3 km) to the left (southeast). Continuing 0.2 mile (0.3 km) farther, a road to the right (northwest) descends into the gorge below the dam; and 0.3 mile (0.5 km) still farther, the main road crosses the top of the dam.

The parking area along Clarksville Road in the center of the emergency overflow spillway (OH-WA-0001) is located at 39°28'49"N, 84°03'25"W (4373976 m N, 753156 m E, UTM zone 16), on the Oregonia, Ohio, 7.5-minute quadrangle. (This area has not been surveyed into townships and ranges.) The topmost exposed strata lie at an elevation of 925 ft (281.9 meters). Clarksville Road crosses the floor of the emergency spillway at an elevation in the center of 883 ft (269.1 meters) above sea level.

Much of the following discussion is taken from Schumacher and others (1987), and Shrake and others (1988), and Shrake (1992). Paleoenvironmental interpretations are from Schumacher and Ausich (1983).

The emergency spillway is 2,667 ft (813.1 meters) long and 450 ft (137.2 meters) wide, giving the spillway an area of over 1.2 million square feet (112,000 square meters), which is equivalent to more than 27 acres (11 hectares).

The exposure below the dam, called Caesar Creek gorge (OH-WA-0002), is reached via the winding road 0.8 mile (1.3 km) long descending to a parking lot in the bottom of the deep valley of Caesar Creek itself; the outcrop is at the lefthand (north) end of the bottom of the dam, 0.1 mile (0.2 km) from that lot. The shale bank there is at 39°29'05"N, 84°03'49"W (4374458 m N, 752555 m E, UTM zone 16). Its base is at an elevation of 755 ft (230.1 meters).

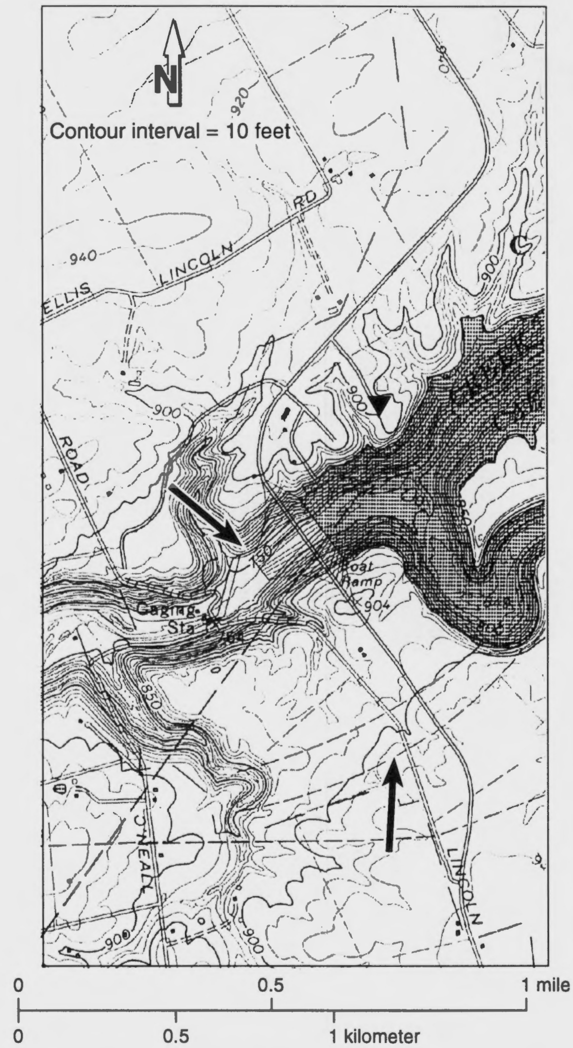

FIGURE 13-1.—Location of the Caesar Creek sites. The spillway is indicated by the southern arrow, the shale bank below the dam by the northern arrow, and the Visitors Center by the solid triangle. Oregonia, Ohio, 7.5-minute quadrangle.

As mentioned above, even though this locality is within a state park, the general public is permitted to collect fossils from the emergency spillway, although excavation is not allowed. The only requirement is to sign a permit form at the Visitors Center each time one wishes to collect. For further information and current rules, write or call:

Caesar Creek Lake Visitors Center
U.S. Army Corps of Engineers
4020 N. Clarksville Road
Waynesville, Ohio, 45068
513-897-1050

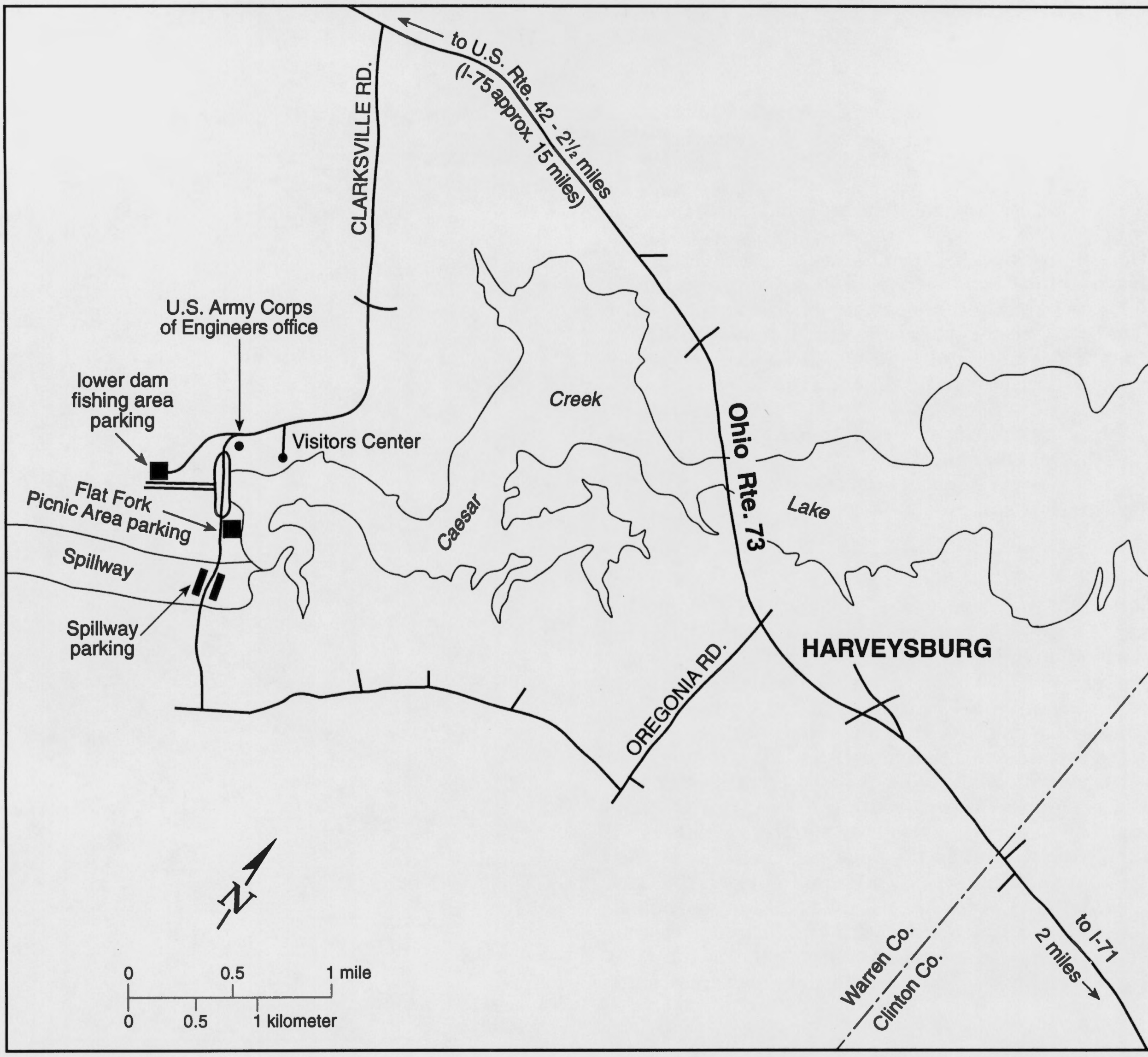

FIGURE 13-2.—Diagrammatic road net in vicinity of the Caesar Creek spillway and dam (from Shrake, 1992).

Caesar Creek Lake Ranger Station
(same address)
513-897-1738

Caesar Creek State Park Office
Ohio Department of Natural Resources
8570 E. State Route 73
Waynesville, Ohio, 45068
513-897-3055.

STRATIGRAPHY

The Caesar Creek localities have been described by Schumacher and Ausich (1983), Schumacher and others (1987), Shrake and others (1988), and Shrake (1992). Further discussion of the formations exposed here can be found in Schumacher (paper 16 in this volume). The stratigraphic units exposed are illustrated in figure 13-3.

At the base of the dam approximately 10 ft (3.3 meters) of the Arnheim Formation and about 40 ft (12.2 meters) of the Waynesville Formation are exposed. This outcrop is excellent for studying the Arnheim Formation's nodular-bedded, rubbly weathering nature and its contact with the overlying Waynesville Formation.

The Arnheim Formation is traditionally separated into two members, the basal Sunset and overlying Oregonia. Only about 10 ft (3.3 meters) of the Oregonia is exposed at the dam. The Oregonia Member averages 60 percent shale and 40 percent limestone. The limestone in the Oregonia Member occurs as thin (1.5 inches/3.8 cm), discontinuous, wavy beds and as nodules (1 to 3 inches/2.5 to 7.6 cm in diameter), intermixed and interbedded with fissile shale layers. The member was named for exposures near Oregonia, Ohio, 3 miles (4.8 km) southwest of the park. Field mapping in Warren County indicates the uppermost portion of the Oregonia Member is a consistent waterfall former and tends to have a rubbly weathering pattern.

Approximately 40 ft (12.2 meters) of the basal Waynesville

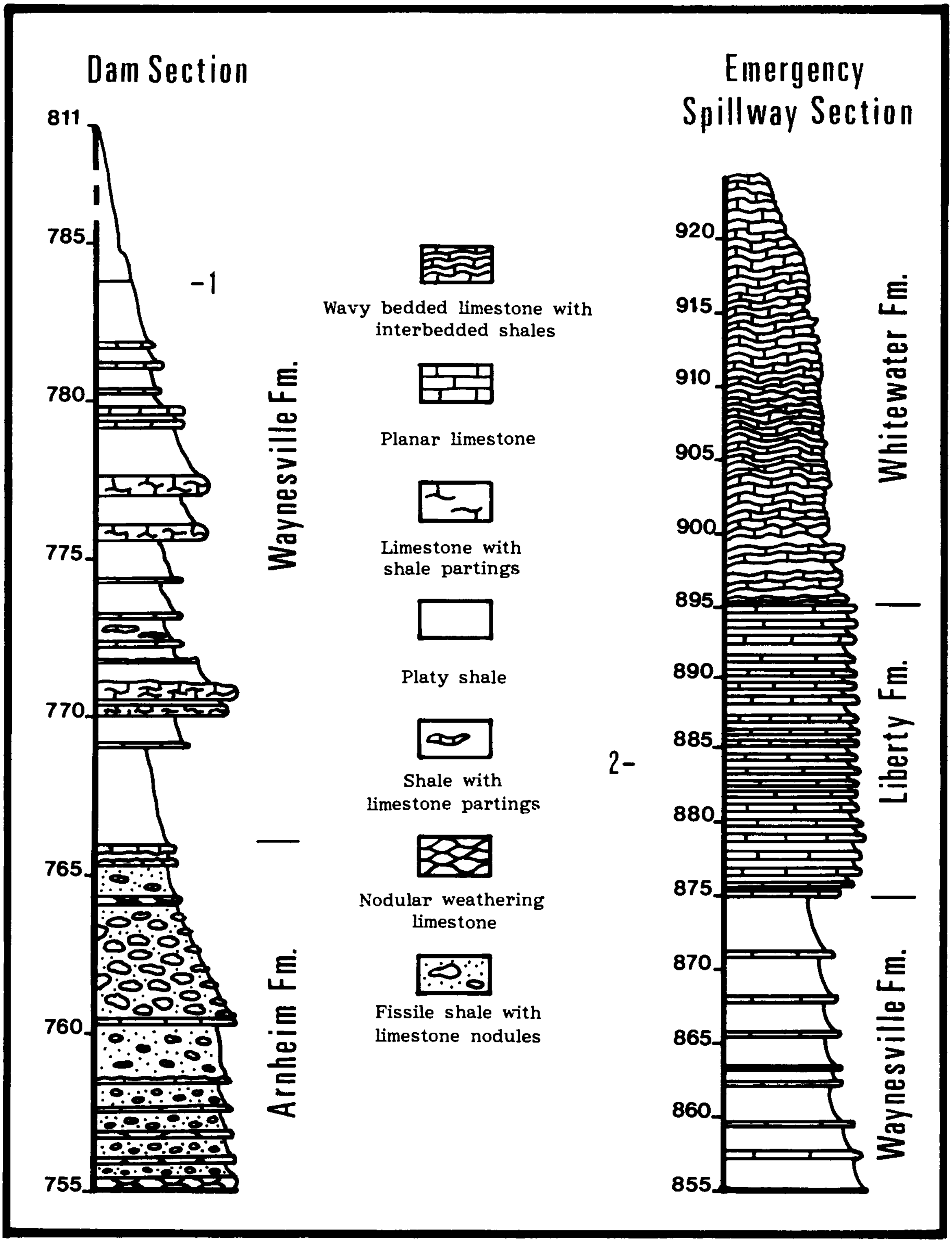

FIGURE 13-3.—Stratigraphic sections exposed at Caesar Creek dam. Vertical numbers indicate feet above sea level. 1 = Waynesville Formation poorly exposed above bench from about 784 ft (239.0 meters) to the top of the outcrop at about 811 ft (247.2 meters); 2 = Clarksville Road at approximately 883 ft (269.1 meters) (modified from Shrake and others, 1988, p. 42):

Formation overlies the Arnheim Formation at the dam section (fig. 13-3). In northeastern Warren County, the Waynesville averages about 110 ft (34 meters) in thickness and is 74 percent shale and 26 percent limestone. Thick (5 inches/12.7 cm), platy-parted shale layers are interbedded with thin (2 inches/5 cm), planar, moderately continuous limestone layers. The type area for the Waynesville Formation includes the outcrops of the unit in the vicinity of Waynesville, Ohio.

At the emergency spillway, the floor and walls expose the sequence from the top of the Waynesville Formation to the basal portion of the Whitewater Formation. The formations are distinguished by the ratio of limestone to shale, the style of bedding, and the thickness of the individual layers. Examination of the bedding styles visible in the spillway walls is encouraged; however, climbing on the vertical walls is strictly prohibited by the Corps of Engineers.

The upper 20 ft (6 meters) of the Waynesville is exposed along the southwestern end of the emergency spillway but is covered by colluvium. These strata are predominantly calcareous blue-gray shales with fossiliferous, gray limestone lenses (packstones). This portion of the spillway section is generally interpreted to have been deposited in a lower energy environment below normal wave base with periodic disturbances by storms. Supporting evidence for a lower energy environment consists of a lack of wave-rippled limestones, shingled brachiopods, broken and abraded fossils, and cross-bedded limestones. However, the presence of graded beds, partly winnowed limestones, and well-preserved echinoderms indicates that high-energy sedimentologic events such as storms influenced the unit periodically. Kreisa and others (1981) reported evidence of storms in Caesar Creek limestones.

The Liberty Formation is exposed in the emergency spillway floor and walls (fig. 13-3). The formation averages 27 ft (8.2 meters) thick and 57 percent shale and 43 percent limestone (packstones and grainstones). The Waynesville Formation and the Liberty Formation are distinguished by the percentage of limestone (26 vs. 43 percent) and by thickness of the limestone layers (2 inches/5 cm vs. 4 inches/10 cm).

The Liberty Formation represents a transitional zone between the lower energy Waynesville below and the higher energy Whitewater above. This interpretation is based on the increased number of limestone beds that have been winnowed of most, if not all, of the silt- and clay-size material, the presence of rare wave-rippled limestones and shingled brachiopods, and an increase in abraded and broken fossils from the Waynesville.

Although the Whitewater Formation averages 66 ft (20 meters) in thickness in northeastern Warren County, only the basal 30 ft (9.1 meters) is exposed along the emergency-spillway wall and the overlying slope (fig. 13-3). The Whitewater averages 52 percent shale and 48 percent limestone in northeastern Warren County. However, the basal section exposed in the park is 45 percent shale and 55 percent limestone. Limestone layers in the Whitewater Formation are thin (2 inches/5 cm), wavy bedded, discontinuous, and argillaceous. Shale layers are thin and fissile.

Higher energy conditions are inferred for the Whitewater on the basis of abundant completely winnowed limestones (grainstones), lower faunal diversity, and an increase in encrusting bryozoans, cross-laminations, and abraded fossils.

No Saluda dolomite has been mapped in Warren County. Its approximate horizon presumably would be at the top of the spillway section, based on extrapolations of thickness trends from the west.

PALEONTOLOGY

Some of the more common fossils at Caesar Creek spillway include the rugose coral *Grewingkia canadensis*; the bryozoans *Parvohallopora subnodosa* and *Constellaria polystomella*; the brachiopods *Platystrophia*, *Hebertella*, *Onniella meeki*, *Rafinesquina alternata*, *Hiscobeccus capax* (formerly referred to *Lepidocyclus*), *Strophomena*, *Zygospira modesta*, and *Leptaena richmondensis*; the pelecypods *Ambonychia radiata* and *Cymatonota typicalis*; the nautiloid cephalopod *Treptoceras duseri*; and the gastropods *Cyclonema bilix* and *Trochonema*. Less common are the trilobites *Flexicalymene meeki*, *Isotelus*, *Acidaspis onealli*, *Chasmops breviceps*, and *Ceraurinus icarus* and the echinoderms *Cupulocrinus*, *Cincinnaticrinus*, *Dendrocrinus*, *Gaurocrinus*, *Xenocrinus*, *Lichenocrinus*, and *Petraster*. In addition to providing a classic locality to collect body fossils, the emergency spillway provides an excellent opportunity to study many of the trace fossils of the local Cincinnatian rocks, such as *Rusophycus*, *Chondrites*, and *Diplocraterion*. Examples of these fossils can be seen on the weathered limestone slabs in the talus along the southern wall of the spillway. Well-preserved echinoderms from several horizons in the spillway have been described by Schumacher and Ausich (1983).

The Whitewater limestones and shales here yield abundant robust branching bryozoans, especially at the top of the main road cut on the southeastern side of the spillway. The Whitewater is generally interpreted to be of very shallow water origin (Cuffey, paper 2 in this volume, fig. 2-4). A modern analog for abundant ramose bryozoans on extremely shallow carbonate bottoms can be seen off South Cat Cay in the Bahamas (Hoffmeister and others, 1967, p. 180, 183, 185; Cuffey and Fonda, 1976); a comparable example on terrigenous sediments was examined in 1977 by Cuffey off St. Theresa Beach in the panhandle of Florida. Branching bryozoans can also be important in deeper waters, at mid-shelf depths, as documented by Lagaaij and Gautier (1965, p. 52, 54) and Schopf (1969, p. 237, 240), but such occurrences are clearly different from these Whitewater deposits. Abundant branching bryozoans thus are not simplistically indicative of deeper waters (as commonly seems to be presumed), but can be found in certain shallow habitats as well.

Such great bryozoan abundance warrants investigation; hence, approximately 200 colony fragments were examined and identified (Rockwell and Cuffey, 1996). Thirty-seven species were found in the highest exposed Whitewater strata here, a comparatively high biodiversity for this phylum at a single locality within the type-Cincinnatian. Bryozoans identified (* denotes species constituting 5 percent or more of this bryozoan fauna) included many trepostomes: the monotrypid *Cyphotrypa madisonensis*; the monticuliporids *Gortanipora bassleri*, *Homotrypa alta*, *H. austini*, *H. cincinnatiensis*, *H. communis*, *H. creditensis*, *H. cylindrica*, *H. nitida*, *H. nodulosa*, *H. richmondensis*, *H. wortheni*, *Homotrypella rustica*, and *Peronopora pachymura*; the amplexoporids *Amplexopora variabile* and *Rhombotrypa quadrata**; the heterotrypids *Heterotrypa cystata*, *H. inflecta*, *Dekayia semipilaris*, and *Leptotrypa minima*; the halloporids *Hallopora congrua**, *H. dalei*, *H. elegantula*, *H. nodulosa*, *Parvohallopora ramosa**, *P. rugosa*, *P. subnodosa**, *P.*

subplana, and *P. wesenbergiana*; the trematoporid *Batostoma varians**; and the batostomellids *Batostomella meeki*, *Bythopora dendrina**, and *Eridotrypa mutabilis*. Three bifoliate cryptostomes (*Arthropora cleavelandi**, *Crateriopora lineata*, and *Dicranopora emacerata*) and one paleotubuliporine cyclostome (*Cuffeyella arachnoidea*) are also present (Taylor and Wilson, 1996). (*Parvohallopora ramosa* and *P. rugosa* may be conspecific; their distributions do overlap, but they do not coincide. It is important to record each variant wherever it turns up, because that eventually may tell us what each was. For example, perhaps the variants are a reflection of local variation in microhabitat.)

Before the Caesar Creek spillway was excavated, the bryozoans of the Whitewater Formation had been studied by Cumings (1908) and by Utgaard and Perry (1964). Thus, this fauna has been sampled extensively, but independently three times. Approximately two-thirds of the species found in each study appear in one or both of the others, indicating substantial but not complete overlap among these three investigations. Moreover, in order to assess possible sampling effects upon the understanding of the local faunal composition in these fossils, the Caesar Creek bryozoans were collected as two separate equal-sized subsamples. Again, about two-thirds of Caesar Creek's total of 37 species occur in each subsample, but only half are present in both; however, if the numbers of specimens identified are counted instead of just the species, a much greater overlap (about 80 percent) is seen. The seven most common Caesar Creek species all appear in both subsamples, most in Cumings (1908), and half in Utgaard and Perry (1964).

As noted above, the bryozoan-bearing beds at Caesar Creek are chronologically correlative with the Saluda Dolomite to the west, the bryozoans of which also have been analyzed recently (Butler and Cuffey, 1994, 1996; papers 6 and 14 in this volume). There is a total of 42 bryozoan species at this horizon across the Cincinnati region. The high diversity at Caesar Creek, as contrasted with the lower diversity in the Saluda itself, nicely fits with the paleoenvironmental interpretation of a shallow, open-marine shelf for this locality (Cuffey, Butler, and Rockwell, 1996).

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Addresses of authors: Gregory A. Schumacher, Douglas L. Shrake, and E. Mac Swinford, Ohio Department of Natural Resources, Division of Geological Survey, 4383 Fountain Square Drive, Columbus, OH 43224-1362; and Lynn A. Rockwell and Roger J. Cuffey, Department of Geosciences (Deike Bldg.), Pennsylvania State University, University Park, PA 16802.

14. ARNHEIM THROUGH UPPER WHITEWATER STRATA AT THE MADISON-INDIANA ROUTE 56 ROAD CUTS (UPPER ORDOVICIAN, SOUTHEASTERN INDIANA)

by
Donald E. Hattin and Roger J. Cuffey

SIGNIFICANCE

The road cuts along Indiana Route 56, where the road ascends the valley wall up from the Ohio River just west of Madison, expose the longest continuous section of Ordovician rocks in Indiana (Hattin and others, 1961, p. 328). Although one or two more recent cuts now may exceed this section somewhat in length, it is still well exposed and abundantly fossiliferous and continues to be an important locality for examining later Cincinnatian formations in the region. This section can be compared profitably with that exposed in the relatively recent cuts along U.S. Route 421 northeast of Madison (IN-JE-0001, IN-JE-0002, and IN-JE-0003; see Hay, Totten, and Cuffey, paper 6 in this volume).

LOCATION

This locality (IN-JE-0004) consists of four closely spaced road cuts along Indiana Route 56 (formerly also Indiana Route 62) at various distances east or downgrade from its junction with the present Indiana Route 62 about 4 miles (6.4 km) west of downtown historic Madison, Jefferson County, Indiana (fig. 14-1):

1. 0.3-0.7 mile (0.5-1.1 km) east of intersection,
2. 0.8 mile (1.3 km) east of intersection,
3. 0.9 mile (1.4 km) east of intersection, and
4. 1.0-1.2 miles (1.6-1.9 km) east of intersection.

The most conspicuous cut is the high wall exposing the Saluda Limestone at the sharp curve 0.5-0.6 mile (0.8-1.0 km) east of that junction. The cuts occupy the NE corner sec. 6 and N$\frac{1}{2}$N$\frac{1}{2}$NW$\frac{1}{4}$ sec. 5, T. 3 N., R. 10 E., and S$\frac{1}{2}$SW$\frac{1}{4}$ SE$\frac{1}{4}$ sec. 31, T. 4 N., R. 10 E., on the Madison West, Indiana–Kentucky, 7.5-minute quadrangle. The high cut through the Saluda is situated at 38°44'12"N and 85°26'28"W (4288480 m N, 635461 m E, UTM zone 16).

STRATIGRAPHIC SECTION

The following section (fig. 14-2) was measured in 1957 by Donald E. Hattin and published (as Stop 8 of field trip 9) in Hattin and others (1961, p. 343-347). Only the most abundant fossils or fossil groups are listed, and names of taxa have been updated, where appropriate (R. A. Davis, 1992, written commun.).

Middle and Lower Silurian units, 52.6 ft (16.0 meters) exposed

UPPER ORDOVICIAN

	feet	(meters)
<u>(Upper) Whitewater Formation</u>		
dd. Limestone, dark gray, fine to medium grained, with brachiopods, gastropods, cephalopods, ostracodes, and stromatoporoids, and shale, dark gray, calcareous, laminated (several stromatoporoid heads are erosionally truncated)	5.2	(1.6)
Total thickness of Whitewater	**5.2 ft**	**(1.6 m)**
<u>Saluda Limestone</u>		
cc. Dolomitic limestone, light gray to greenish gray, fine to coarse grained, local geodes, many calcite-filled worm? burrows, contains ramose bryozoans (all those sectioned being *Batostomella*		

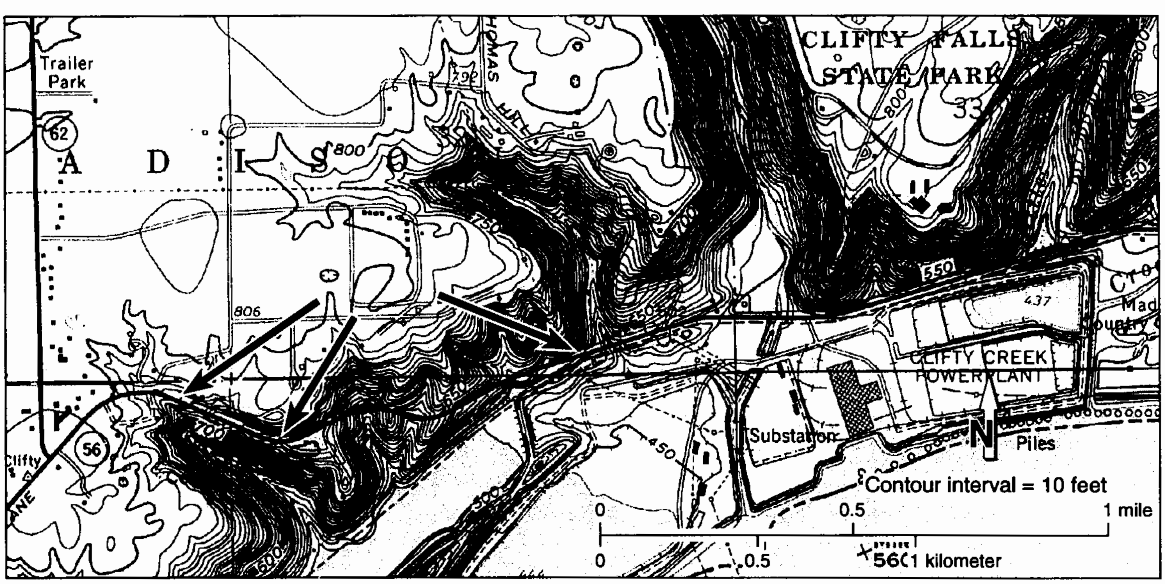

FIGURE 14-1.—Location of the Indiana Route 56 road cuts; the western and eastern arrows indicate the extent of the cuts and the middle arrow indicates the high cut through the Saluda Limestone. Madison West, Indiana–Kentucky, 7.5-minute quadrangle.

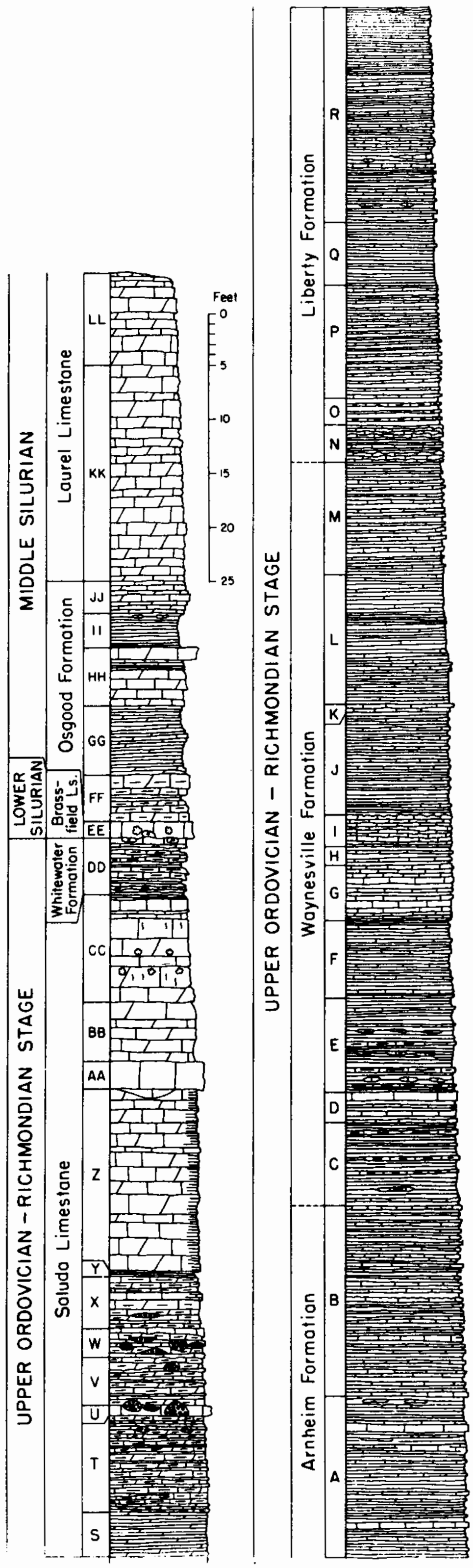

FIGURE 14-2.—Graphic section of strata exposed in the Indiana Route 56 road cuts west of Madison, Indiana (from Hattin and others, 1961, p. 328, fig. 11); current Indiana Geological Survey usage would label beds A-R as the Dillsboro Formation.

delicatula, according to Butler and Cuffey, 1996) 10.1 (3.1)

bb. Dolomitic limestone, light olive gray to greenish gray, fine grained, silty 5.4 (1.6)

aa. Limestone, light olive gray, argillaceous, fine grained, many calcite-filled worm? burrows 2.5 (0.8)

z. Dolomitic limestone, grayish yellow green, laminated, fine grained, silty, glauconitic in lower part 16.9 (5.2)

y. Shale, olive gray, glauconitic, laminated 0.6 (0.2)

x. Dolomitic limestone, light olive gray, fine-grained, silty, with abundant ramose bryozoans, *Strophomena*, and local *Tetradium* 4.7 (1.4)

w. Limestone and dolomitic limestone, olive gray to dark gray, fine grained, with numerous *Tetradium* and fewer *Favistina*; unit biostromal 2.7 (0.8)

v. Dolomitic limestone, olive gray, fine grained, silty, with thin layers of limestone, dark gray, fine to coarse grained, abundant fossil fragments; unit contains some *Favistina*, bryozoans, and brachiopods 4.5 (1.4)

u. Dolomitic limestone, olive gray, fine grained, silty, with numerous *Favistina*; unit biostromal 1.0 (0.3)

t. Dolomitic limestone, olive gray, fine grained, silty, very argillaceous, soft to hard, locally shaly, with numerous thin beds of hard, fine- to coarse-grained, gray limestone; unit contains numerous *Grewingkia*, *Rafinesquina*, *Strophomena*, *Platystrophia*, *Hebertella*, *Hiscobeccus* (also referred to *Lepidocyclus*), ramose bryozoans, and a layer of *Favistina* near top 4.5 (1.4)

s. Dolomitic mudstone, medium light gray, silty, weathers blocky 4.1 (1.2)
Total thickness of Saluda 57.0 ft (17.4 m)

Liberty Formation

r. Clay shale, greenish gray to olive gray, gritty, very calcareous, and limestone, medium dark gray, fine to coarse grained; unit contains *Grewingkia*, abundant articulate brachiopods and ramose bryozoans, and much shell debris 20.0 (6.1)

q. Clay shale, pale olive to greenish gray, gritty, very calcareous, weathers blocky, limestone in middle like that in unit "r"; unit contains abundant articulate brachiopods, ramose and massive bryozoans, and pelecypods 5.9 (1.8)

p. Limestone, medium gray, medium to coarse grained, biofragmental, and shale, greenish gray, very calcareous; unit contains gastropods, pelecypods, articulate brachiopods, ramose bryozoans, and *Grewingkia* 10.6 (3.2)

o. Clay shale, olive gray, gritty, very calcareous, with thin layers of calcareous claystone; unit contains brachiopods and bryozoans 2.5 (0.8)

n. Limestone, medium gray, fine to coarse grained, biofragmental, and lime mudstone, fine grained, with few fossils; unit has thin olive-gray clay-shale interbeds and numerous brachiopods, ramose and massive bryozoans, and *Grewingkia* 3.4 (1.0)

Total thickness of Liberty 42.4 ft (12.9 m)

Waynesville Formation - upper limit indefinite

m. Clay shale, medium gray to light olive gray, very calcareous, and limestone, light brownish gray, medium to coarse grained, biofragmental; unit contains *Grewingkia*, *Isotelus*, massive and ramose bryozoans, articulate brachiopods, and gastropods 10.3 (3.1)

l. Clay shale, olive gray to greenish gray, gritty, very calcareous, completely transitional to argillaceous, highly fossiliferous limestone; unit contains some hard, medium-gray biofragmental limestone; wide variety of fossils litter slope, abundant *Onniella* 12.2 (3.7)

k. Limestone, medium dark gray, fine to coarse grained; unit contains articulate brachiopods and ramose and massive bryozoans 0.7 (0.2)

j. Clay shale, greenish gray, somewhat gritty, very calcareous, with numerous layers of limestone, medium gray, medium to coarse grained, biofragmental; unit contains abundant *Onniella*, other articulate brachiopods, ramose and massive bryozoans, gastropods, and *Grewingkia* 9.5 (2.9)

i. Limestone, medium dark gray, medium to coarse grained, biofragmental, with thin calcareous shale breaks; unit contains *Onniella*, other articulate brachiopods, pelecypods, and massive bryozoans 3.1 (0.9)

h. Clay shale, weathered moderate yellowish brown, moderately calcareous, with four thin limestones, light brownish gray, fine to medium grained, biofragmental; unit contains gastropods, *Onniella*, other articulate brachiopods, and ramose bryozoans 1.7 (0.5)

g. Limestone, medium gray, medium to coarse grained, biofragmental, with thin shale partings; unit contains *Onniella*, other brachiopods, and gastropods 5.1 (1.6)

f. Clay shale, light olive gray, moderately calcareous, abundant fossil fragments, with beds of limestone like those in unit "g"; unit contains *Onniella*, other brachiopods, pelecypods, gastropods, trilobites, and ramose bryozoans 7.2 (2.2)

e. Clay shale, dusky yellow, moderately calcareous, few fossils, with nodular claystone in lower part and thin limestone beds as in unit "g" 8.6 (2.6)

d. Limestone, medium to dark gray, coarse grained, biofragmental, with interbeds of calcareous, gritty, clay shale 2.8 (0.9)

c. Clay shale, weathered dusky yellow, blocky, moderately calcareous, with two thin limestones and a few lime-mudstone nodules; unit contains crinoid columnals 7.7 (2.3)

Total thickness of Waynesville 68.9 ft (21.0 m)

Arnheim Formation - upper limit indefinite

b. Limestone, medium gray to light brownish gray, coarse grained, biofragmental, with nearly equal quantity of clay shale, greenish gray, highly calcareous; unit contains profusion of *Rafinesquina*, other brachiopods, trilobites, bryozoans, crinoid columnals, pelecypods, *Cyclonema*, and other gastropods 17.2 (5.2)

a. Clay shale, greenish gray, moderately calcareous, with two thick beds of limestone, light to dark gray, coarse grained, biofragmental, with numerous thin layers and nodules of limestone, argillaceous, fine to medium grained; unit not so fossiliferous as unit "b"; unit contains articulate brachiopods, pelecypods, and ramose bryozoans minimum thickness 10.6 (3.2)

Total thickness of exposed Arnheim 28.8 ft (8.8 m)

Total thickness of measured section 253.9 ft (77.4 m)

STRATIGRAPHIC NOTES

The following comments on Richmondian stratigraphy in southeastern Indiana are mainly those written by Hattin for a field trip for the 1961 Cincinnati meeting of the Geological Society of America (Hattin and others, 1961, p. 328-331, Stop 8); taxonomic names have been updated (R. A. Davis, 1992, written commun.).

The lowest part of the section, separated from the upper part by a 25-foot (7.6-meter) covered interval, is exposed at the foot of the hill beside a small cafe on the north side of the road. Upper Maysvillian beds at the cafe are not included in the measured section. Strata of the lower part of the Richmond group consist of a sequence of alternating fossiliferous limestones and generally less fossiliferous shales. These beds have been classed, in upward order, as Arnheim, Waynesville, and Liberty formations wholly on paleontological criteria and are not formations in the restricted sense of the term. Arnheim guide fossils include *Homotrypa bassleri* and *Retrosirostra carleyi* in combination with conspicuous numbers of *Cyclonema bilix* and *Flexicalymene meeki*. The Arnheim contains a proportionately greater quantity of limestone than the overlying Waynesville. Chief guide fossil of the Waynesville Formation is *Onniella meeki*, which abounds on some bedding planes. Species that occur in conspicuous numbers in the formation are *Leptaena richmondensis*, *Zygospira modesta*, and *Thaerodonta clarksvillensis*. *Glyptorthis insculpta* is common in a zone at the top of the formation that was classed as Liberty by Cumings (1908). Waynesville strata are generally more shaly than beds above or below, but sharp contacts cannot be drawn on a lithologic basis.

In the Liberty Formation, *Rhombotrypa quadrata*, a ramose bryozoan, is an abundant and characteristic species (Cuffey and Perry, 1964). *Hiscobeccus capax* (formerly referred to the genus *Lepidocyclus*), *Strophomena planumbona*, and *Grewingkia canadensis* are more abundant in the Liberty than in adjacent strata.

Ordovician formations above the Liberty can be distinguished readily on lithologic character alone. In the Madison, Indiana, area, the Saluda is characteristically dolomitic, is chiefly medium bedded to very thick bedded, and contains abundant quartz silt that dominates insoluble residues of most beds. The only characteristic Saluda fossils are *Favistina stellata* and *Tetradium approximatum*. The former generally is confined to the lower, and the latter to the upper, of two biostromes that lie near the base of the formation. For many years the contact between the Liberty and Saluda formations of the Madison area has been defined as the base of the lower of the two coral biostromes. However, such a contact segregates as Liberty much dolomitic rock that is related genetically to the Saluda environment of deposition. Although the biostromes provide a convenient and natural base for the Saluda north of Madison, southward from Madison these coral beds terminate laterally well above the base of a section of thick-bedded dolomitic limestone that is typical of the Saluda. The contact between the Saluda is diachronous and descends the section southward from Madison. If the Saluda is to be considered a lithogenetic unit, then it is necessary to place the contact at the base of these dolomitic strata, for this is the most reliable and logical boundary between Liberty and Saluda beds in the southern part of the Indiana outcrop. A thin, widespread, dark-gray glauconitic shale (unit Y; fig. 14-2) serves as a key marker bed in demonstrating the contact relationship between the two formations and serves as the datum for the cross section in figure 14-3. At Marble Hill, at the south end of the cross section, 34 ft (10.4 meters) of thick-bedded, not visibly fossiliferous dolomitic limestone lies below the shale marker bed. At Madison (3, Clifty Power Plant, on fig. 14-3), 25.8 ft (7.9 meters) of fossiliferous dolomitic limestone and mudstone lies beneath the key bed. At Versailles, only 8.1 ft (2.5 meters) of dolomitic limestone, constituting the *Tetradium* biostrome, lies beneath the key bed. From south to north the base of the Saluda grades into progressively higher nondolomitic and highly fossiliferous beds of the upper Liberty formation.

Lying above the key shale bed are laminated, thick-bedded to very thick bedded dolomitic limestones that thin progressively northward from Jefferson County, Indiana. Ripple marks and mud cracks are common in the laminated beds, but Hattin has seen no fossils in these beds. The lower part of the laminated beds passes northward from Madison into a thin sequence of alternating shales and medium- to thick-bedded limestones. Highest of the widespread Saluda marker beds is a resistant bed, or group of beds, that forms the lip of many high waterfalls in the area between Bethlehem and Versailles, Indiana. Vertical cylinders of calcite in this bed are probably spar-filled burrows of worms. The *Tetradium* biostrome, laminated beds, and "falls lip" bed of the Madison area constitute a bundle of rock units that can be traced farther northward than any other Saluda beds. Above the "falls lip" limestone bed is 15.5 ft (4.7 meters) of thick-bedded to very thick bedded dolomitic limestone that passes northward, by lateral gradation, into strata typical of the Whitewater formation. The Whitewater-Saluda contact, like the Liberty-Saluda contact, is diachronous, transcending time lines from north to south.

The Saluda is mostly a poorly fossiliferous, chiefly dolomitic limestone wedge that lies between, and is partly gradational with, highly fossiliferous, nondolomitic strata. North of Versailles, beds assigned to the Saluda constitute an essentially nondolomitic facies that can be traced as far north as Hamburg, beyond which the formation is unrecognizable. Near Laurel, Indiana, 9 miles (14.5 km) north of Hamburg, beds in the position of the Saluda are a highly fossiliferous, thin-bedded shale and limestone sequence that contains an abundance of stromatoporoids and compound corals.

Saluda features such as laminated bedding, oscillation ripple marks of short length and low amplitude, mud cracks, and general lack of fossils suggest that the formation is the product of quiet, shallow-water deposition, possibly in a stagnant or a highly saline environment. In contrast, biofragmental limestones above and below the Saluda represent high-energy, well-oxygenated environments where normal-marine faunas flourished. The association of biostromal units with lower Saluda beds through much of the Indiana outcrop, and abundance of biostromes in the vicinity of the northern terminus of the formation, suggest a relationship between the biostromes and the environment in which the Saluda facies was deposited. Although much more field, subsurface, and laboratory work needs to be accomplished, we tentatively suggest that Saluda deposition was linked with lagoonal conditions that existed behind low but extensive shoal areas on which banks of *Favistina*, *Tetradium*, and stromatoporoids grew extensively. (See Hatfield, 1968, and Laribee, 1994, for further elaboration of these suggestions.)

The lower strata of the Saluda here contain numerous

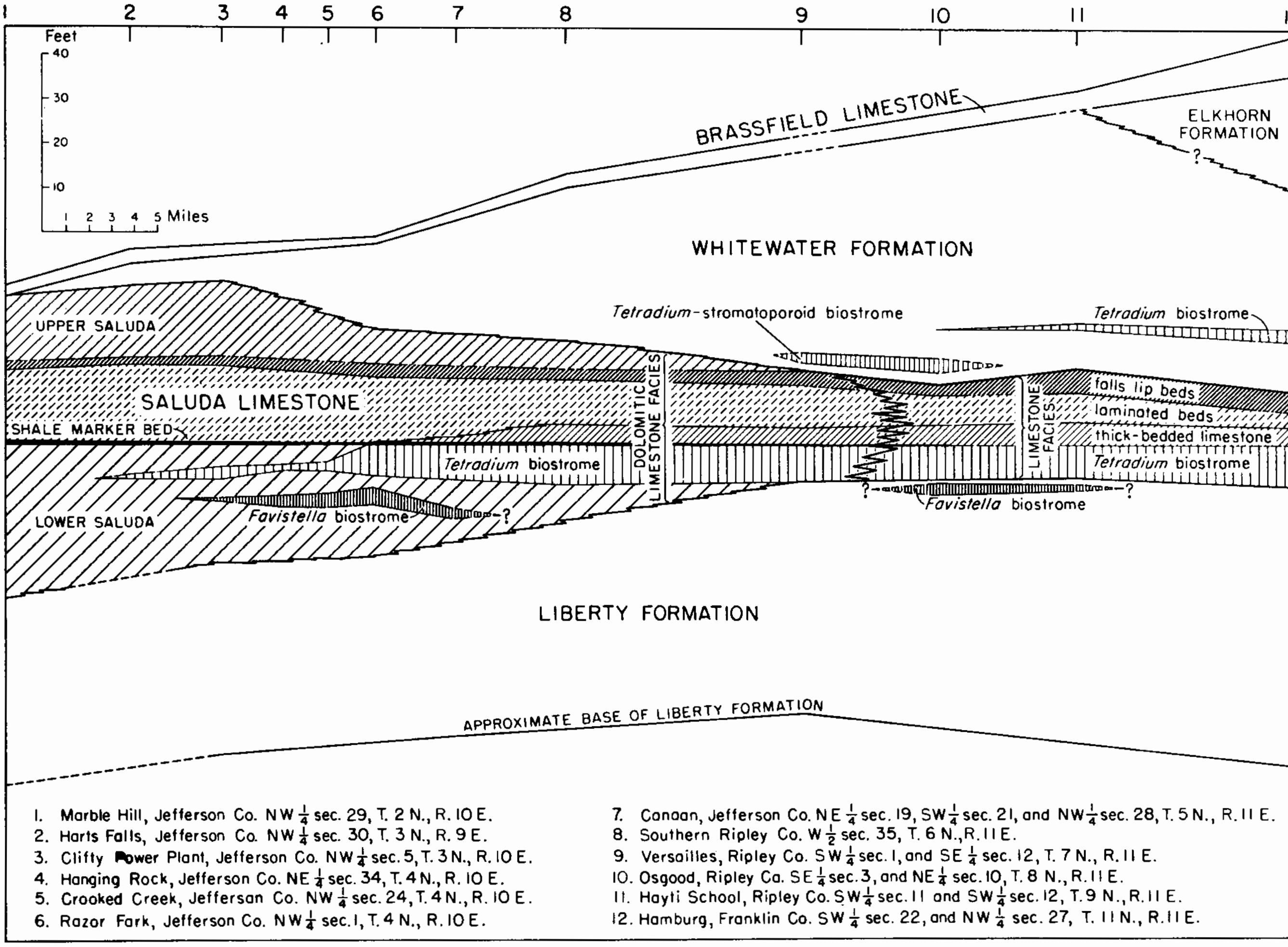

FIGURE 14-3.—South-north cross section in southeastern Indiana showing the stratigraphic relations of the Saluda Limestone (from Hattin and others, 1961, p. 330, fig. 12). The Madison-Indiana Route 56 outcrop is equivalent to 3, Clifty Power Plant.

bryozoans, but, in contrast to the diversity in the rest of the type-Cincinnatian, only three species are represented here, *Homotrypa cincinnatiensis*, *Rhombotrypa quadrata*, and *Heterotrypa subfrondosa* (Butler and Cuffey, 1994, 1996). The Saluda correlates with the bryozoan-rich mid-Whitewater beds at Caesar Creek (Rockwell and Cuffey, 1996; paper 13 in this volume). The Saluda's reduced bryozoan diversity, in contrast to the high diversity at Caesar Creek, reflects well the hypersaline shelf-lagoon paleoenvironment inferred for the Madison area at this horizon (Cuffey, Butler, and Rockwell, 1996).

Whitewater strata are generally thin and very irregularly bedded as compared with underlying Saluda beds. Although *Rhynchotrema dentatum* has been cited as a characteristic Whitewater fossil, specimens are very rare south of Hamburg, Indiana. *Platystrophia acutilirata* is a common species in the northern part of the Indiana outcrop. The stromatoporoid *Labechia huronesis* is very common in the Whitewater and forms local biostromes. Algal biostromes are well developed in the formation near Richmond, Indiana. At most exposures, the Whitewater contains large numbers of the smooth-shelled ostracode *Leperditia*. The Whitewater thins southward along the Indiana outcrop by progressive gradation of the lower beds into the upper Saluda and seemingly by regional erosional truncation of the upper beds. The unit cannot be recognized in Indiana sections south and west of Harts Falls (fig. 14-3). The name "Hitz bed" (Foerste, 1903) has been applied to the thin but highly fossiliferous Whitewater section in the area around Madison, Indiana.

Northward from northern Ripley County, the Elkhorn formation, youngest of the Richmondian formations in the type area, lies between the Whitewater and the Brassfield (Silurian) formations. We tentatively conclude from field studies that the Elkhorn terminates southward by lateral gradation into the upper Whitewater formation and by erosional truncation of the upper beds. Little is known or published concerning the Elkhorn fauna, but the entire section is exposed in several places south and southwest of Richmond, Indiana.

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Addresses of authors: Donald E. Hattin, Department of Geological Sciences, Indiana University, 1005 East 10th Street, Bloomington, IN 47405; and Roger J. Cuffey, Department of Geosciences (Deike Bldg.), Pennsylvania State University, University Park, PA 16802.

15. THE WHITEWATER FORMATION ON U.S. ROUTE 27 NEAR RICHMOND (UPPERMOST ORDOVICIAN, EAST-CENTRAL INDIANA)

by
Helen B. Hay and Roger J. Cuffey

SIGNIFICANCE

The part of the Whitewater Formation exposed in the U.S. Route 27 road cut about 1 mile (1.6 km) south of Richmond, Indiana (fig. 15-1), is significant because it provides a good and readily accessible exposure of the rubbly, thin-bedded facies that is most characteristic of the formation and because it furnishes some of the youngest, richly fossiliferous strata available within the type-Cincinnatian. Although the Whitewater Formation contains other facies (fig. 15-2), it is this particular lithology that constitutes the greatest volume of the formation and by which it is readily identified at other localities around the margin of the outcrop area. This part of the formation also is exposed and accessible along Sim Hodgin Parkway (IN-WY-0003) in the Whitewater Gorge through Richmond, at Thistlethwaite Falls (IN-WY-0006) at the northern termination of the gorge on the West Fork of the East Fork of the Whitewater River, and in the Short Creek road cut (IN-WY-0002) just east of the Richmond-U.S. Route 27 cut.

The strata at this road cut are laterally equivalent to the Saluda Formation at Garr Hill (IN-FR-0003) (see Hay and Cuffey, paper 11 in this volume); the Saluda pinches out between Garr Hill and Richmond (Hay, 1981). Because the Saluda dolomite constitutes a lens within the Whitewater (see figs. 2-3 and 2-4 in Cuffey, paper 2 in this volume), there has been a tendency to divide the Whitewater into "lower" and "upper" parts, depending on whether the strata are below or above the Saluda or the Saluda horizon. As noted later in this paper, the Richmond-U.S. Route 27 road cut therefore includes rock of both the lower and upper portions of the Whitewater. Complicating this terminology, however, is recent recognition of additional Ordovician strata above the Elkhorn Shale (fig. 15-2; also see Schumacher, paper 16 in this volume), which was long considered the topmost Ordovician in the region.

The remainder of the Whitewater Formation is exposed at the other localities indicated on figures 15-1 and 15-2; the most significant localities are scattered outcrops along Elkhorn Creek between Straight Line Road (Pike) and Indiana Route 227. The creek is on private property and is not readily accessible; moreover, it generally is also heavily overgrown. The Ordovician/Silurian contact is exposed at the base of Elkhorn Falls (IN-WY-0004) just west of where Elkhorn Creek intersects Indiana Route 227; this site also is on private property. Relatively unfossiliferous shale, presumably but not certainly the Elkhorn, can be seen underneath the Silurian Brassfield Limestone forming the lip of Elkhorn Falls, but only when the creek waters are low.

All these localities mentioned constitute the Richmond composite section, which thus extends from the Liberty Member of the "Brookville formation" up through the Whitewater Formation—the uppermost Ordovician of this area—to the Silurian contact (fig. 15-2).

LOCATION

Lower and upper Whitewater strata are exposed in the road cut on U.S. Route 27, 1.2-1.3 miles (1.9-2.1 km) southwest of its junction with Indiana Route 227 on the south edge of Richmond, Wayne County, Indiana (IN-WY-0001) (fig. 15-1). This road cut is located in NW$^1/_4$SE$^1/_4$SW$^1/_4$ sec. 17, T. 13 N., R. 1 W., on the Richmond, Indiana, 7.5-minute quadrangle, at 39°47'13"N and 84°54'10"W (4406000 m N, 679610 m E, UTM zone 16).

STRATIGRAPHY AND INTERPRETATION OF THE RICHMOND COMPOSITE SECTION

Figure 15-2 presents the stratigraphic units and lithofacies of the Richmond composite section and places the U.S. Route 27 road cut within that context. Lithofacies (fig. 15-3) and formation names are discussed by Hay (1981, and paper 17 in this volume). The Whitewater Formation, as defined here, includes all strata between the top of the Liberty Member of the "Brookville formation" and the Ordovician/Silurian boundary; the Elkhorn Shale here is considered to be a member of the Whitewater Formation. It makes sense to include strata above the Elkhorn Shale in the Whitewater Formation because facies 3c, the most typical Whitewater facies, occurs both above and below the shale. Except for the fact that the upper occurrence of facies 3c is cemented with dolomite, it is identical to that in the lower part of the Whitewater at the U.S. Route 27 locality. Strata that are lithologically transitional between Liberty and Whitewater are included in the Whitewater. The total thickness of the Whitewater Formation here is about 34 meters (113 ft). Descriptions of each locality in the composite section are provided by Hay (1981).

The Richmond composite section correlates with Garr Hill near Brookville, Indiana (see Hay and Cuffey, paper 11 in this volume). The *Thaerodonta* peak zone at about 7 meters (23 ft) above the base at Garr Hill correlates both faunally and lithologically with the base of the Richmond composite section. The Saluda Formation at Garr Hill should be equivalent to about the lower or middle part of the U.S. Route 27 road cut, although no Saluda facies occur at Richmond.

THE U.S. ROUTE 27 ROAD CUT

Figure 15-2 presents the stratigraphic units and lithofacies along U.S. Route 27 and figure 15-4 indicates the distribution of fossils in partially equivalent strata at Thistlethwaite Falls (IN-WY-0006) at the north edge of Richmond. Two facies, 3b and 3c (see fig. 15-3) are exposed at the U.S. Route 27 road cut. Facies 3c is the typical rubbly, thin-bedded argillaceous limestone containing irregular lumps of limestone separated by thin seams of limy terrigenous clay and silt. It can be difficult to tell limestones from shales, and accurate bed-by-bed measurements are virtually impossible. The overall insoluble content is about 33 percent, on the basis of acid treatment of bulk samples, and the carbonate content of "shales" is as much as 56 percent. It is this poor separation of siliciclastics and carbonates that is the distinctive characteristic of this facies and causes its properties. The rubbly weathering of the facies is caused by clay seams that coat and separate irregular limestone nodules. Very thin, irregular bedding is evident when the out-

FIGURE 15-1.—Location of the Richmond-U.S. Route 27 road cut (**US27** and arrow). Richmond, Indiana, and New Paris, Ohio–Kentucky, 7.5-minute quadrangles. Other localities (stars) that constitute the Richmond composite section are: **EC**, Elkhorn Creek (IN-WY-0008); **EF**, Elkhorn Falls (IN-WY-0004); **MF**, Middlefork Reservoir (IN-WY-0007); **SC**, Short Creek (IN-WY-0002); **SR**, Sub Run (IN-WY-0005); and **TF**, Thistlethwaite Falls (IN-WY-0006).

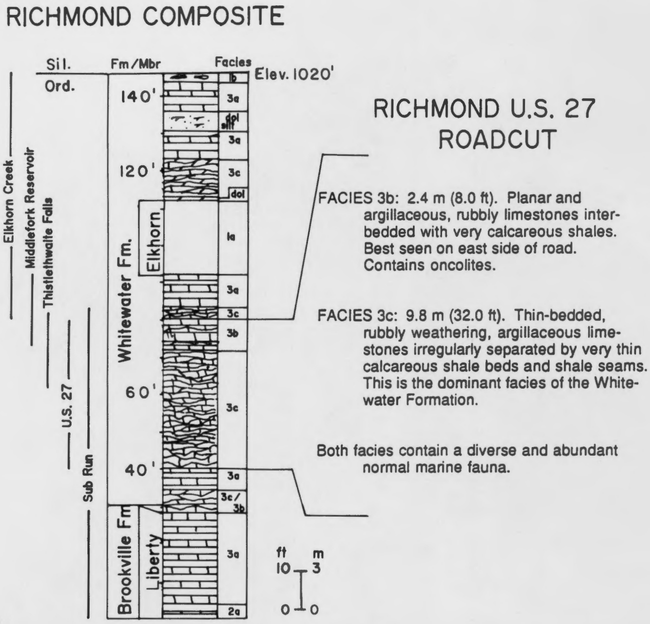

FIGURE 15-2.—Stratigraphy of the Richmond-U.S. Route 27 road cut in the context of the entire Richmond composite section: Elkhorn Creek (IN-WY-0008), Middlefork Reservoir (IN-WY-0007), Sub Run (IN-WY-0005), and Thistlethwaite Falls (IN-WY-0006). See Hay (1981) for detailed descriptions of these other sites. See figure 15-3 for description of lithofacies.

crop is viewed from a distance.

Thin sections of facies 3c show that these rocks have a higher proportion of whole fossils and large fossil fragments and a smaller percentage of sand- and silt-size allochems compared with facies such as 3a or 2a that have well-segregated limestone and shale beds. The thin sections also show abundant evidence of algae and micritic matrix compared with other facies.

Facies 3b at the top of the outcrop is best seen along the east side of the road. It is like facies 3c except that some of the limestones are thicker, more planar, and less argillaceous than those of facies 3c. Some of the limestones of this facies contain abundant algal oncolites.

These two facies also constitute most of the Bellevue Member of the Grant Lake Formation (Schumacher and others, 1991) in southern Indiana and Ohio and northern Kentucky. Although both facies are present, facies 3b is more common in the Bellevue, whereas facies 3c is more common in the Whitewater.

ENVIRONMENTS

The characteristics of facies 3c, in general, suggest that it probably formed in very shallow, but not strongly agitated water, perhaps the interior of a broad shoal. This interpretation is consistent with a number of properties of the rock: the poor separation of limestones and shales into discrete beds, the high proportion of large allochems, the low proportion of fine allochems, the abundant micrite, and the presence of algae. Facies 3b probably formed in a slightly higher energy environment marginal to the platform, which would explain the thicker, more planar, less clayey limestones produced by storm segregation of coarser allochems and fine siliciclastics into separate limestone and shale beds. This environment of slightly higher energy than facies 3c is consistent with the presence of oncolites in facies 3b. The interpretation of a very shallow environment also is consistent with the stratigraphic relation of this facies to the Saluda Formation (Hay, paper 17 in this volume).

Both facies contain an abundant and diverse normal-marine fauna (fig. 15-4). Large trepostome bryozoans constitute the greatest volume of the rock and may have helped protect the sediment from reworking by waves and currents. Mollusks are probably next in abundance, particularly clams and snails that occur as steinkerns. The brachiopods are commonly articulated, which again points to a relatively quiet environment. Corals also are common.

ADDITIONAL LOCALITIES

Other localities that constitute the Richmond composite section (figs. 15-1 and 15-2; see Appendix A for descriptions) include:

Elkhorn Creek (IN-WY-0008).

Elkhorn Falls (IN-WY-0004).—Unfossiliferous gray shale (0.3 meter/1 ft) is exposed under low waterfalls just west of the Indiana Route 227 bridge over Elkhorn Creek. The falls are formed by the Silurian-age Brassfield Limestone. This shale was long thought to represent the Elkhorn Shale, but possibly may be an unnamed shale higher up, in the Brassfield Limestone. Otherwise, about 3 meters (10 ft) of Brassfield Limestone is exposed. Private property.

Middlefork Reservoir (IN-WY-0007).

Short Creek/Straight Line Pike (IN-WY-0002).—The same strata present at the Richmond-U.S. Route 27 locality also are exposed 0.7 mile (1.1 km) to the east, in the small road cut where Straight Line Pike (Road) crosses Short Creek. The road cut has yielded unusually large colonies, up to 15 cm (6 inches) across by 7 cm (3 inches) high, of the trepostome bryozoan *Monticulipora epidermata* Ulrich and Bassler, 1904, which are being studied by G. Hillmer and R. J. Cuffey.

Sim Hodgin Parkway (IN-WY-0003).

Sub Run (IN-WY-0005).

Thistlethwaite Falls (IN-WY-0006).—Figure 15-4 shows the stratigraphic ranges of important fossils in this outcrop.

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Addresses of authors: Helen B. Hay, deceased, formerly Department of Geology, Earlham College, Richmond, IN 47374; and Roger J. Cuffey, Department of Geosciences (Deike Bldg.), Pennsylvania State University, University Park, PA 16802.

Principal diagnostic characteristics of lithofacies		
Group 1 >70% shale	1a	Well-bedded, mostly thin limestones and medium to thick, fissile to blocky shales. Includes massive units of 100% shale. Low-diversity fauna.
	1b	Rubbly, shaly, nodular limestones; medium to thick shales with limy stringers and layers of fossils in shale matrix. May have some well-bedded limestones as in 1a. Low-diversity fauna. Most easily seen in cores.
Group 2 55-70% shale	2a	Like 1a except has high diversity of fauna. Intermediate in shale percentage between 1a and 3a.
	2b	Well-bedded limestones, rubbly nodular limestones, and limy shales. Allochems tend to be more finely broken than 2a. High-diversity fauna. Intermediate between 3a and 3c.
Group 3 <55% shale	3a	Well-bedded, thin to medium limestones and thin to medium, fissile to blocky shales. High-diversity fauna.
	3b	Well-bedded, thin to medium limestones with or without rubbly or nodular shales. High-diversity fauna. Intermediate between 3a and 3c.
	3c	Thin-bedded, rubbly weathering, argillaceous limestones, very thin limy shales. High-diversity fauna.
	3d	Limestones and shales as in 3a except >20% of limestones are fine-grained laminated burrowed, barren of large fossils; trails on tops. Grade to siltstones.
Group 4 Miscellaneous	4a	High-angle cross-bedded calcarenites, bimodal dip. Little or no shale.
	4b	Granule-size fossils in thick to massive beds; little or no shale. May be like 4a if seen in similar outcrops.
	4c	Massive *Loxoplocus* limestone bed. Marble Hill Bed.
	4d	Bioturbated light-gray limestone with low-diversity fauna of ostracodes, algae, snails, and *Tetradium*. Related to Saluda facies complex.

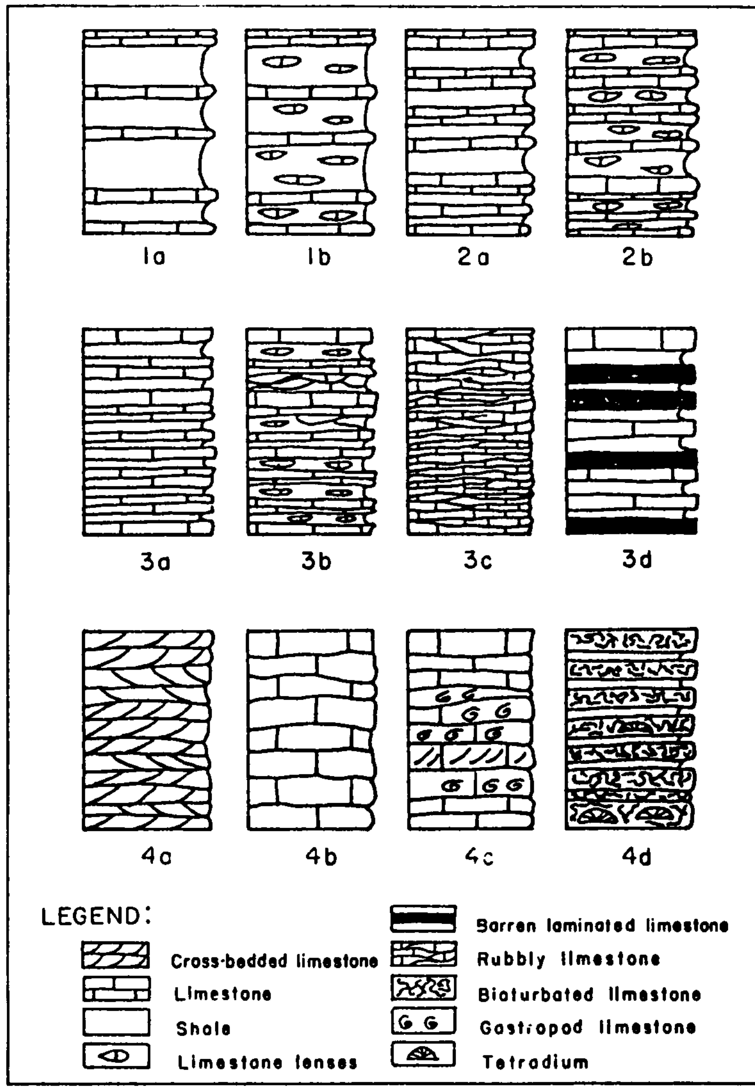


FIGURE 15-3.—Lithofacies characteristics. (see Hay, paper 17 in this volume).

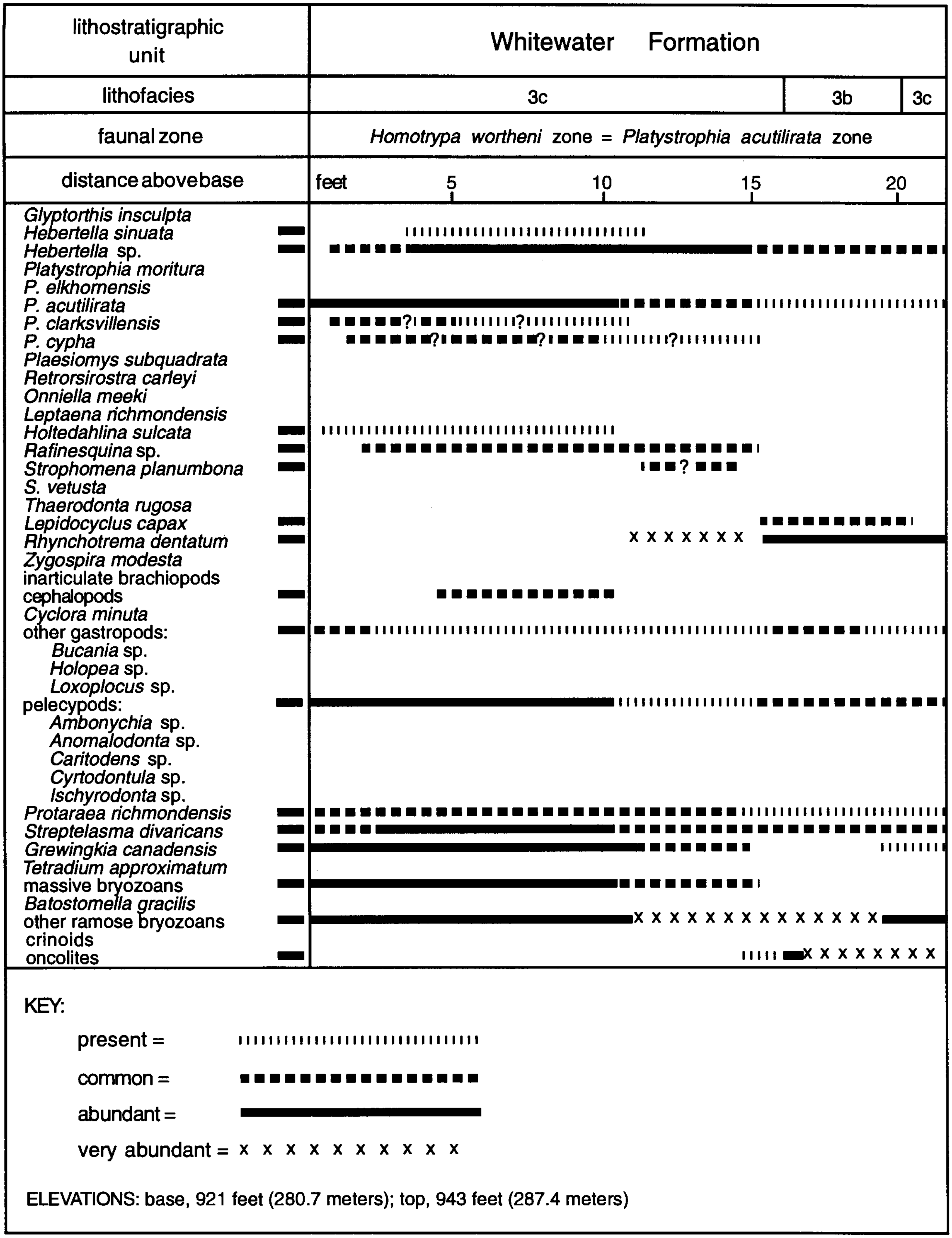


FIGURE 15-4.—Fauna of Thistlethwaite Falls (IN-WY-0006), which is partially equivalent to the Richmond-U.S. Route 27 site (modified from Hay, 1977, p. I-16, fig. I-6). Note that *Lepidocyclus capax* was assigned to the genus *Hiscobeccus* by Amsden (1983).

16. A NEW LOOK AT THE CINCINNATIAN SERIES FROM A MAPPING PERSPECTIVE

by
Gregory A. Schumacher

INTRODUCTION

The interpretation of the geology and paleontology of the Upper Ordovician Cincinnatian Series has been evolving for over a century and a half. Drake (1825) was the first to publish an account of geology in the Ohio River valley of southwestern Ohio. In the 170+ years following this publication, hundreds of investigations have been carried out on various geological and paleontological aspects of the rocks of the Cincinnatian Series (see Appendix B at the end of this volume).

Most of these studies focused on a local geographical area or described and discussed the taxonomy of a group of fossils (for example, James, 1886; Nickles, 1902; Foerste, 1903; Caster and Kjellesvig-Waering, 1964; Ford, 1967; Warn and Strimple, 1977). In the last decade or two, a number of geological investigations have examined the regional geology of the Cincinnatian Series using measured stratigraphic sections and lithofacies analysis (Hay, 1981; Tobin, 1982) or bedrock geologic mapping supplemented by measured stratigraphic sections and continuous cores (Weir and others, 1984; Schumacher, Swinford, and Shrake, 1991), or graptolite and conodont biostratigraphy (Bergström and Mitchell, 1990a, 1990b; Mitchell and Bergström, 1991).

This body of geological and paleontological literature provides an excellent framework to build upon in taking a new look at the geology of the Cincinnatian Series using modern mapping and geological concepts. The Ohio Department of Natural Resources, Division of Geological Survey, in conjunction with The Ohio State University, have been reexamining the Cincinnatian Series of southwestern Ohio. Geologists with the Ohio Division of Geological Survey have been conducting detailed bedrock geologic mapping, measuring and describing stratigraphic sections and cores, interpreting geophysical logs, and studying conodont biostratigraphy. Researchers at The Ohio State University have examined the graptolite and conodont biostratigraphy. Our efforts have resulted in: (1) the mapping of the Cincinnatian Series in Ohio at a scale of 1:24,000, (2) the measurement and description of 100 stratigraphic sections, (3) the drilling, measurement, and description of 32 continuous cores, (4) the interpretation of 95 suites of geophysical logs, and (5) the development of biostratigraphic control on portions of nine cores. These data serve as the basis for our ongoing revision and refinement of the understanding of the surficial and subsurface lithostratigraphy, graptolite and conodont biostratigraphy, and depositional setting of the Cincinnatian Series of southwestern Ohio.

LITHOSTRATIGRAPHY

HISTORICAL BACKGROUND

The lithostratigraphic nomenclature of the Cincinnatian Series has been, and continues to be, a point of debate. This debate centers on whether the units originally described by Orton (1873), Nickles (1902, 1903), Foerste (1903, 1905, 1909), Bassler (1906), and Cumings (1908) are interpreted as biostratigraphic units or as having a major lithostratigraphic component as well as a biostratigraphic component. The original stratigraphic units are collectively termed traditional stratigraphic units. In figure 16-1, the stratigraphic column of Caster and others (1955) illustrates the traditional units.

The traditional stratigraphic units were accepted and used to describe the stratigraphy of the Cincinnati, Ohio, region until the 1960's. Beginning in the middle 1960's, some stratigraphers (for example, Brown and Lineback, 1966; Peck, 1966; Hatfield, 1968; Gray, 1972) abandoned the traditional stratigraphic units because they concluded that these units were defined as biostratigraphic units (fig. 16-1). They abandoned the traditional units in accordance with Article 6 of the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961), which states that formal lithostratigraphic units should be based on lithology not on fossil content or fossil ranges.

On the other hand, a second group of stratigraphers believed the traditional units were defined in both a lithologic and biostratigraphic context and chose to retain these units redefined to the standards of the Code of Stratigraphic Nomenclature (for example, Ford, 1967; Tobin, 1986; see fig. 16-1). Some stratigraphers developed informal lithostratigraphic nomenclatures using a combination of traditional units and new lithostratigraphic units (for example, Lee, 1974; Hay, 1981; see fig. 16-1). Also, the reexamination of traditional stratigraphy led to the recognition of the Grand Avenue Member and Wesselman Tongue of the Kope Formation, the North Bend Tongue of the Fairview Formation, and the Miamitown Shale (Ford, 1967).

CURRENT LITHOSTRATIGRAPHY

The Ohio Division of Geological Survey decided to test the mappability of the updated traditional stratigraphic units of Ford (1967) and Tobin (1986) and to examine the merits of reinstating the name Cincinnati Group for the Late Ordovician rocks of Ohio. Many of these units, including the Miamitown Shale of Ford (1967), were found to be mappable over all or part of southwestern Ohio.

However, as mapping proceeded, it became apparent that certain units were not mappable at all or mappable only at scales of 1:24,000 or larger. These units will be discussed in ascending stratigraphic order beginning with the primarily sub-Cincinnatian Point Pleasant Tongue of the Clays Ferry Formation (fig. 16-2).

Field mapping and subsurface correlation of the Point Pleasant Tongue of the Clays Ferry Formation of Swadley and others (1975) indicate that this unit in southwestern Ohio is not a single, limestone-dominant tongue as recognized in northern Kentucky but consists of a number of limestone- and shale-dominant tongues. These tongues grade northwestward in the subsurface into the brown shales of the "Utica shale" filling the Sebree Trough (Mitchell and Bergström, 1991).

I feel the use of the name Point Pleasant Tongue of the Clays Ferry Formation does not describe the multiple limestone- and shale-dominant tongues present in southwestern Ohio. No formal name has been proposed for this strati-

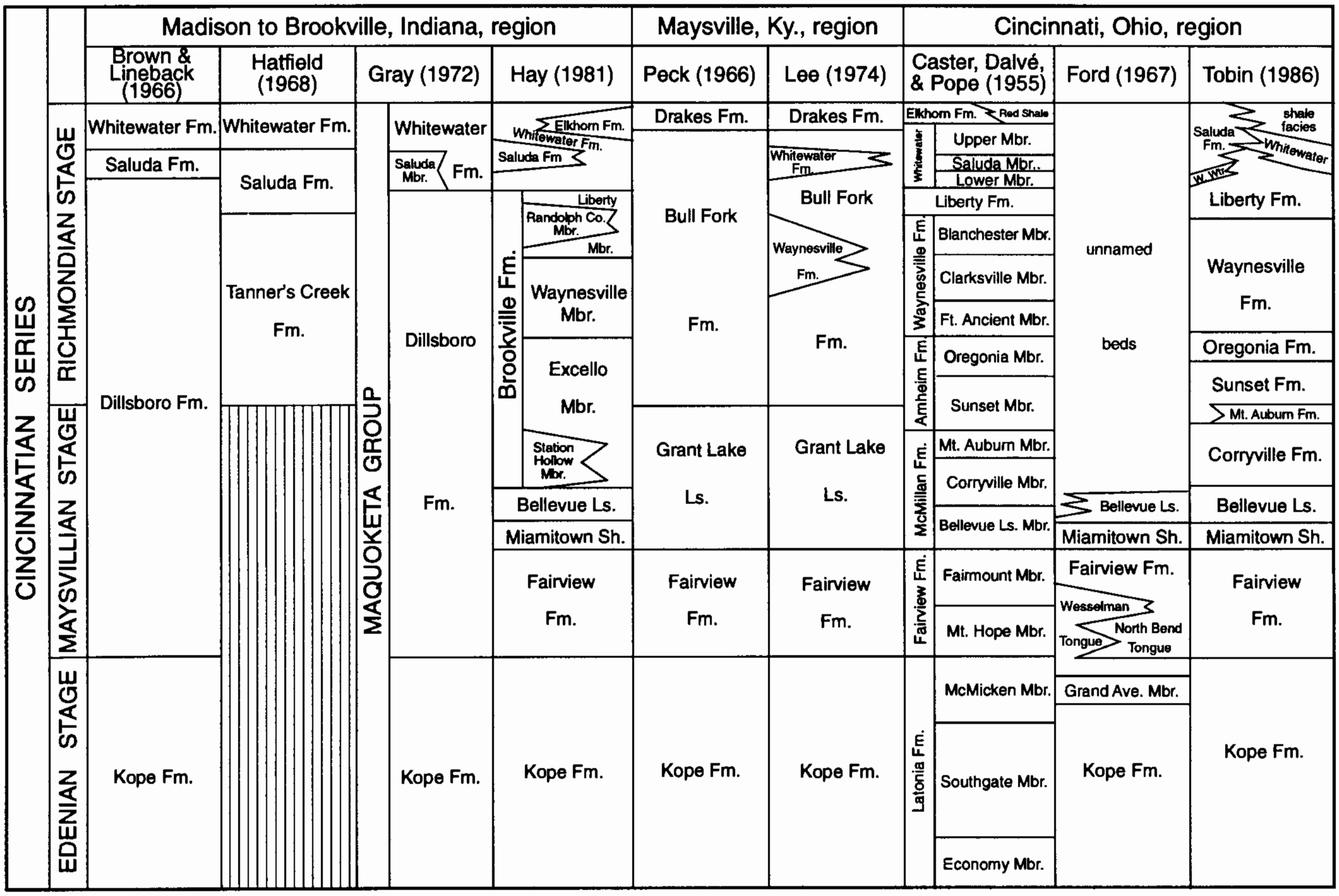


FIGURE 16-1.—Development of the lithostratigraphic nomenclature of the Cincinnati Series in its type area between 1960 and 1990 (modified from Schumacher, 1984, fig. 2).

graphic interval, although the use of the name Point Pleasant Formation is under consideration by the Ohio Division of Geological Survey.

The Bellevue Limestone, the Miamitown Shale, and the Mt. Auburn Formation were mappable, valid units at map scales of 1:24,000 or larger. However, these units would be mapped as solid lines at map scales of 1:62,500 or smaller. Schumacher, Swinford, and Shrake (1991) stated that, at smaller map scales, in areas of high topographic relief, this line would represent the contacts between the Fairview Formation, the Miamitown Shale, the Bellevue Limestone, and the Corryville Formation.

Schumacher, Swinford, and Shrake (1991) also discussed the lithologic changes that take place between the Cincinnati, Ohio, region and the Maysville, Kentucky, region in the Bellevue Limestone, the Corryville Formation, and the Mt. Auburn Formation. The shale-dominant Mt. Auburn Formation grades laterally into a limestone-dominant unit. Also, the entire Bellevue, Corryville, and Mt. Auburn stratigraphic interval becomes increasing limestone dominant toward Maysville.

Schumacher, Swinford, and Shrake (1991) proposed some changes in the existing lithostratigraphic nomenclature to accommodate mapping at 1:62,500 and smaller map scales and to address the lateral lithologic changes present in this interval. They reduced the Bellevue Limestone, the Corryville Formation, and the Mt. Auburn Formation to members of the newly adopted Grant Lake Formation.

This reduction in rank: (1) retained the traditional stratigraphic units defined at the rank used by Bassler (1906), (2) eliminated the problem of multiple stratigraphic units being represented by solid lines at smaller map scales, and (3) provided convenient lithostratigraphic units to trace the lateral changes in lithologies present in these units. The introduction of the Grant Lake Formation provided a lithostratigraphic unit thick enough to map at smaller map scales and addressed the lateral change from a shale-dominant section in the Cincinnati, Ohio, region to a limestone-dominant section in the Maysville, Kentucky, region. The Grant Lake Limestone of Peck (1966) was adopted for the limestone-dominant portion of this section. The Bellevue and Corryville Members were recognized as members in the Grant Lake Limestone, and the new Straight Creek Member was introduced to address the lateral change from the shale-dominant Mt. Auburn Member to a limestone-dominant member in the Maysville, Kentucky, region.

The Sunset and Oregonia Formations of Tobin (1986) were not mappable over much of southwestern Ohio. The lithologies characterizing the Sunset and the Oregonia Formations were recognizable; however, the contact between these units was rarely exposed. The lack of a mappable contact results from a sizeable increase in the amount of shale in the upper part of the Sunset Formation. The large amount of shale weathers rapidly and commonly buries the contact between the Sunset and the Oregonia. The Ohio Division of Geological Survey has informally mapped the

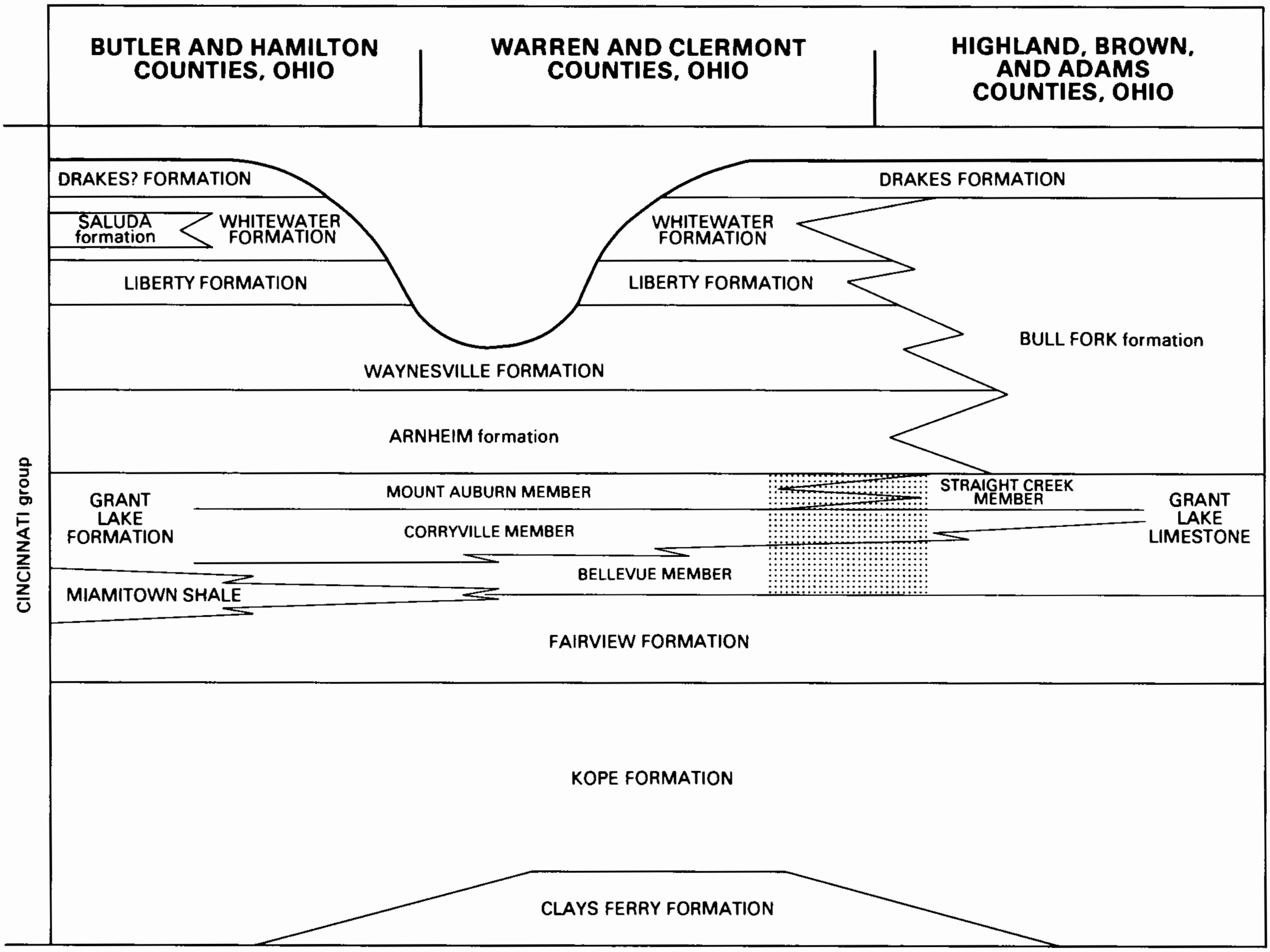


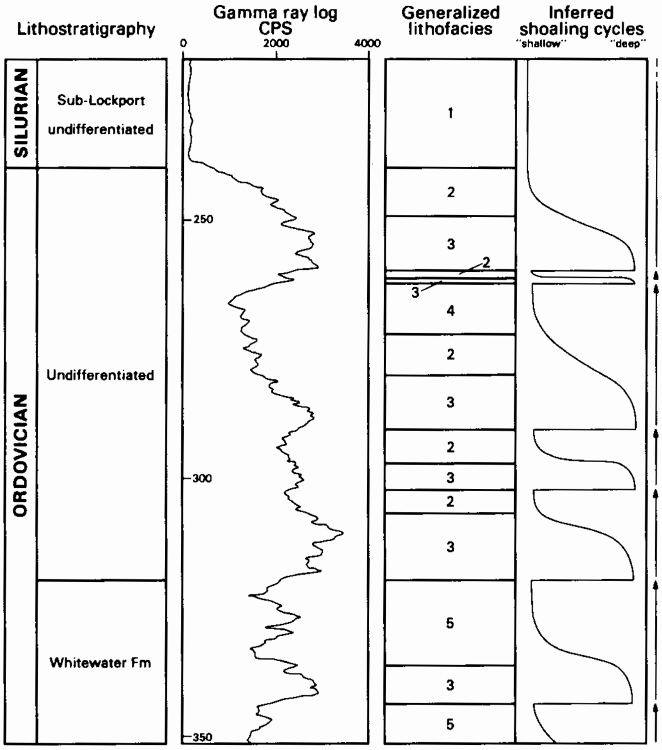
FIGURE 16-2.—Schematic diagram illustrating the Upper Ordovician lithostratigraphic nomenclature in southwestern Ohio as recognized by the Ohio Division of Geological Survey. Formal lithostratigraphic units are indicated by the unit name in upper-case type; informal lithostratigraphic units, by lower-case type. The area under the bold line represents the Upper Ordovician stratigraphic units exposed in the area. The "valley" depicts Late Ordovician or post-Ordovician erosion of the Drakes, Whitewater, and Liberty Formations in Clermont and Hamilton Counties, Ohio. The stippled area is the transition zone between the Grant Lake Limestone and the Grant Lake Formation (from Schumacher, Swinford, and Shrake, 1991, fig. 1).

Arnheim Formation of Foerste (1912) in place of the Sunset and Oregonia Formations. We plan to formalize our use of the Arnheim Formation when field mapping of southwestern Ohio is complete.[1]

The Waynesville, the Liberty, and the Whitewater Formations have been recognized and mapped throughout all or part of Butler, Clermont, Clinton, Greene, Hamilton, Montgomery, Preble, and Warren Counties of southwestern Ohio. The Liberty and Whitewater Formations are not present in Adams, Brown, or Highland Counties of south-central Ohio (fig. 16-2). In south-central Ohio, we have not decided whether to map the "Arnheim" and the Waynesville Formations or use a redefined Bull Fork Formation of Peck (1966) for this area.

The uppermost units of the Cincinnatian Series consist of the Elkhorn Shale of western Ohio and the Preachersville Member of the Drakes Formation in south-central Ohio. The stratigraphic relationships between these two units is poorly understood because of extensive burial by glacial drift along much of the outcrop belt. Recent core drilling conducted by the Ohio Division of Geological Survey in west-central Ohio has provided 10 new stratigraphic sections of this interval. Preliminary study of these cores indicates the presence of a number of repetitive stratigraphic sequences that are easily recognized on gamma ray geophysical logs (fig. 16-3). Each sequence consists of a basal unit (lithofacies 3) of laminated calcareous or dolomitic shale beds and minor interbeds of fossiliferous limestone and dolomite. This unit is overlain by an interval (lithofacies 2) of interlaminated or interbedded limestone and/or dolomite and shale grading into an argillaceous, bioturbated, fine-grained dolomite. These sequences range in thickness from 1 meter (3.3 ft) to over 6 meters (19.7 ft) and are interpreted as repetitive shoaling cycles, possibly as the result of Late Ordovician glaciation. Additional lithologies recognized in this interval include: intervals of massive-bedded, vuggy dolomite (lithofacies 1), intervals of micritic to coarse-grained lime-

[1]Editor's note: Mapping by the Division of Geological Survey in southwestern Ohio has been completed since this paper was written in 1992. The unpublished 1:24,000-scale bedrock-geology, bedrock-topography, and structure-contour maps are on file at the Division.



LITHOFACIES: 1. Massive-bedded, vuggy dolomite.
2. Interbedded or interlaminated dolomite and shale and dolomite; argillaceous with moderate to heavy bioturbation.
3. Shale with rare interbeds of dolomite and limestone.
4. Limestone and dolomite; limestone micritic to coarse grained; dolomite microcrystalline, heavy bioturbation.
5. Interbedded, fossiliferous, wavy-bedded limestone and shale.

FIGURE 16-3.—Preliminary interpretation of the lithostratigraphy, generalized lithofacies, and shoaling cycles present in Ohio Division of Geological Survey core 3066 drilled in Shelby County, Ohio.

stone or microcrystalline, bioturbated dolomite (lithofacies 4), and zones of wavy-bedded limestone and shale (lithofacies 5). Ongoing core drilling will continue to provide additional information to assist in the interpretation of the lithostratigraphy and the depositional environment of this interesting stratigraphic interval.

The Division of Geological Survey is considering reinstating the name Cincinnati Group introduced by Meek and Worthen (1865) for all the strata between the top of the sub-Cincinnatian Lexington Limestone and the Ordovician-Silurian systemic boundary in southwestern Ohio. I feel the name Cincinnati Group would be a useful lithostratigraphic term because: (1) Upper Ordovician rocks in the subsurface of southwestern and south-central Ohio are presently unnamed or misnamed, (2) Upper Ordovician surface and subsurface lithostratigraphic units are not included in one common unit, and (3) the introduction of a lithostratigraphic unit at the group level would avoid possible confusion with the chronostratigraphic unit represented by the Cincinnatian Series. However, the use of the term Cincinnati Group is similar to the term Cincinnatian Series, which may create, not avoid confusion in some geologists' minds. Presently, this issue is under consideration, and I would welcome your suggestions.

BIOSTRATIGRAPHY

HISTORICAL DEVELOPMENT

The fossil content of the interbedded shales and limestones of the Cincinnatian Series is one of the characteristic features of these rocks. This fact was reflected in the original descriptions of the traditional stratigraphic units. For example, Nickles (1902) named the "Mt. Auburn or *Platystrophia lynx* Beds" for the predominantly blue shale with irregularly bedded limestone containing an abundance of the brachiopod *Platystrophia lynx* in the lower 5 to 12 ft (1.5 to 3.7 meters) of this unit. (What was then called *Platystrophia lynx* now is referred to *Platystrophia ponderosa*.) Nickles concluded his description with a faunal list describing the fossils present in the Mt. Auburn beds. This example illustrates the emphasis placed on recognition of fossil constituents and index fossils in the original descriptions of the traditional units. However, systematic collecting to determine the vertical and lateral ranges of the majority of the index fossils of the Cincinnatian Series has yet to be undertaken.

The first truly extensive systematic studies of the vertical and lateral distribution of a group of Cincinnatian index fossils were the conodont biostratigraphic investigations conducted by Ohio State University professor Walter C. Sweet and a host of students (see, for example, Sweet and others, 1959; Pulse and Sweet, 1960; Carpenter and Ory, 1961; Kohut and Sweet, 1968). These studies, along with conodont biostratigraphic studies of the underlying Lexington Limestone (Bergström and Sweet, 1966), resulted in (1) the determination of the stratigraphic ranges of 35 multielement conodont species; (2) the recognition of representatives of conodont faunas inhabiting two distinct faunal provinces, a warm-temperate North American Midcontinent Province, and a cold-temperate Anglo-Scandinavian-Appalachian Province; (3) the development of relative-abundance logs for common Midcontinent species for purposes of regional correlation; and (4) the determination of the vertical ranges of diagnostic species of conodonts from the Upper Ordovician stratotype in order to develop the biostratigraphic framework for the Ordovician System (Sweet and others, 1971).

In the 1970's and 1980's, conodont biostratigraphic investigations focussed on the correlation of other Upper Ordovician stratigraphic sequences to the stratotype. Sweet (1984), using the graphic correlation methods of Shaw (1964), correlated the distribution of conodonts from 61 stratigraphic sections throughout much of the North American Midcontinent Province in order to develop a chronostratigraphic framework for the Mohawkian and Cincinnatian Series. A Composite Standard Section was synthesized and subdivided into 80 vertically continuous, 6-meter (19.7-ft)-thick units representing approximately equal time intervals. These subdivisions, termed Standard Time Units, are believed to represent periods of time 462,500 years in length. When compared to existing chronostratigraphic schemes, these subdivisions increase the resolution by 10 to as much as 27 times.

CURRENT BIOSTRATIGRAPHY

Recent biostratigraphic studies of the Cincinnatian Series in its type area have focussed on graptolite biostratigraphy (Bergström and Mitchell, 1986, 1990a, 1990b; Mitchell and Bergström, 1991). These studies have described the diverse fauna of graptolites from the dark shales present in the subsurface Sebree Trough. This new information has resulted in better definition of the base of the Cincinnatian Series in its type area and allows correlation of these sediments with other graptolite-bearing sequences throughout the world. Stig Bergström (The Ohio State University), Charles Mitchell (State University of New York at Buffalo), and I hope to publish a paper discussing the origin and evolution of the Sebree Trough through time and the tectonic relationships between the Sebree Trough and the Taconic Orogeny.

DEPOSITIONAL ENVIRONMENT

Regional studies of Anstey and Fowler (1969), Hay (1981), and Tobin (1982) have developed the framework necessary to understand the depositional environment of the Cincinnatian Series. These authors have recognized the recurrence of distinctive lithofacies throughout the Cincinnatian Series. These lithofacies were developed as the result of interaction between eustasy, basinal tectonics, and biological productivity. A typical succession ranged from an offshore, "deeper water," shale-dominant lithofacies through a lower shoreface, transitional, mixed limestone and shale lithofacies to an upper shoreface, "shallow-water," limestone- or dolomite-dominant lithofacies. Additional characteristics of each lithofacies are summarized in table 16-1.

The "deeper water" lithofacies was deposited in water depths estimated to have been between 20 and possibly 50 meters (66-164 ft) (Bucher, 1917; Anstey and Fowler, 1969; Anstey and others, 1987). These authors compared Cincinnatian megaripples and bryozoan colony heights to modern analogs to make their paleobathymetric estimates.

Three shoaling cycles (shoaling-upward cycles of some authors) have been recognized in the Cincinnatian Series in the vicinity of Cincinnati, Ohio (Anstey and Fowler, 1969; Hay, 1981; and Tobin, 1982). These authors generally agree in their placement of the beginning and end points of these cycles (fig. 16-4). The first shoaling cycle ranges from the Kope Formation to the top of the Bellevue Member of the Grant Lake Formation. The second, from the base of the Corryville Member of the Grant Lake Formation to the top of the "Arnheim formation," and the third, from the base of the Waynesville Formation to the Ordovician-Silurian systemic boundary.

The lithofacies succession of a given shoaling cycle is readily observed in the field and has been recognized in cores and in shale-percentage and geophysical logs. In the Maysville, Kentucky, region, I have identified five shoaling cycles in the Cincinnatian Series (Schumacher, 1992) (figs. 16-4 and 16-5). I have subdivided the Kope Formation-to-Bellevue Limestone shoaling cycle of previous workers into two cycles on the basis of the presence of a "shallow-water" lithofacies in the base of the Fairview Formation.

The third cycle ranges from the transitional lithofacies in the basal portion of the Corryville Member of the Grant Lake Limestone through the top of the "shallow-water" lithofacies of the Straight Creek Member of the Grant Lake Limestone. The fourth shoaling cycle is from the base to the top of the "Arnheim formation," and the fifth cycle ranges from the basal Waynesville Formation to the top of the Drakes Formation.

I contend that the five shoaling cycles recognized in the Maysville, Kentucky, region also are present in the Cincinnati, Ohio, region. Field mapping supplemented with shale-percentage logs for continuous cores indicates that the "shallow-water" lithofacies of the basal portion of the Fairview Formation in the Maysville, Kentucky, region can be correlated to the North Bend Tongue of the Fairview Formation of the Cincinnati, Ohio, region (fig. 16-5). The "shallow-water" lithofacies present in the Maysville, Kentucky, region grades laterally into a limestone-dominant transitional lithofacies, then to the shale-dominant transitional lithofacies of the North Bend Tongue. This lateral progression of lithofacies illustrates the progressive increase in water depth from Maysville to Cincinnati.

Ford (1967) documented the intertonguing relationship between the shale-dominant transitional lithofacies of the North Bend Tongue of the Fairview Formation and the shale-dominant, "deeper water" lithofacies of the Wesselman Tongue of the Kope Formation. The Wesselman Tongue of the Kope Formation overlying the North Bend Tongue of the Fairview Formation reflects a return to "deeper water" conditions. Thus, the top of the North Bend Tongue of the Fairview Formation is the top of the first shoaling cycle in the Cincinnati region. The lower part of this cycle originates in the middle of the Kope Formation. Laterally, the Wesselman Tongue is overlain by and grades into the shale-dominant transitional lithofacies characterizing the middle part of the Fairview Formation. This lithofacies records the beginning of the second shoaling cycle which ends at the top of the "shallow-water" lithofacies represented by the Bellevue Member of the Grant Lake Formation (fig. 16-5).

Within the second shoaling cycle in the Cincinnati, Ohio, region, the normal progression from the basal, shale-dominant, transitional lithofacies through shallower, limestone-dominant, transitional lithofacies to limestone-dominant "shallow-water" lithofacies is interrupted by the presence

TABLE 16-1.—*Diagnostic features of the lithofacies observed in the Cincinnatian Series of southwestern Ohio*

Lithofacies	Dominant lithology	Subordinate lithology	Dominant lithology bedding		Average range of shale percentage	Fossil content of shales
			Thickness	Style		
"deeper water"	shale	limestone	thick (<.3048 m)	planar	60-100%	sparsely fossiliferous
transitional	interbedded limestone and shale or shale and limestone		medium (between .3048 m and .1016 m)	planar to irregular	40-60%	sparsely fossiliferous
"shallow water"	limestone	shale	thin (>.1016 m)	wavy, nodular, irregular	0-40%	fossiliferous

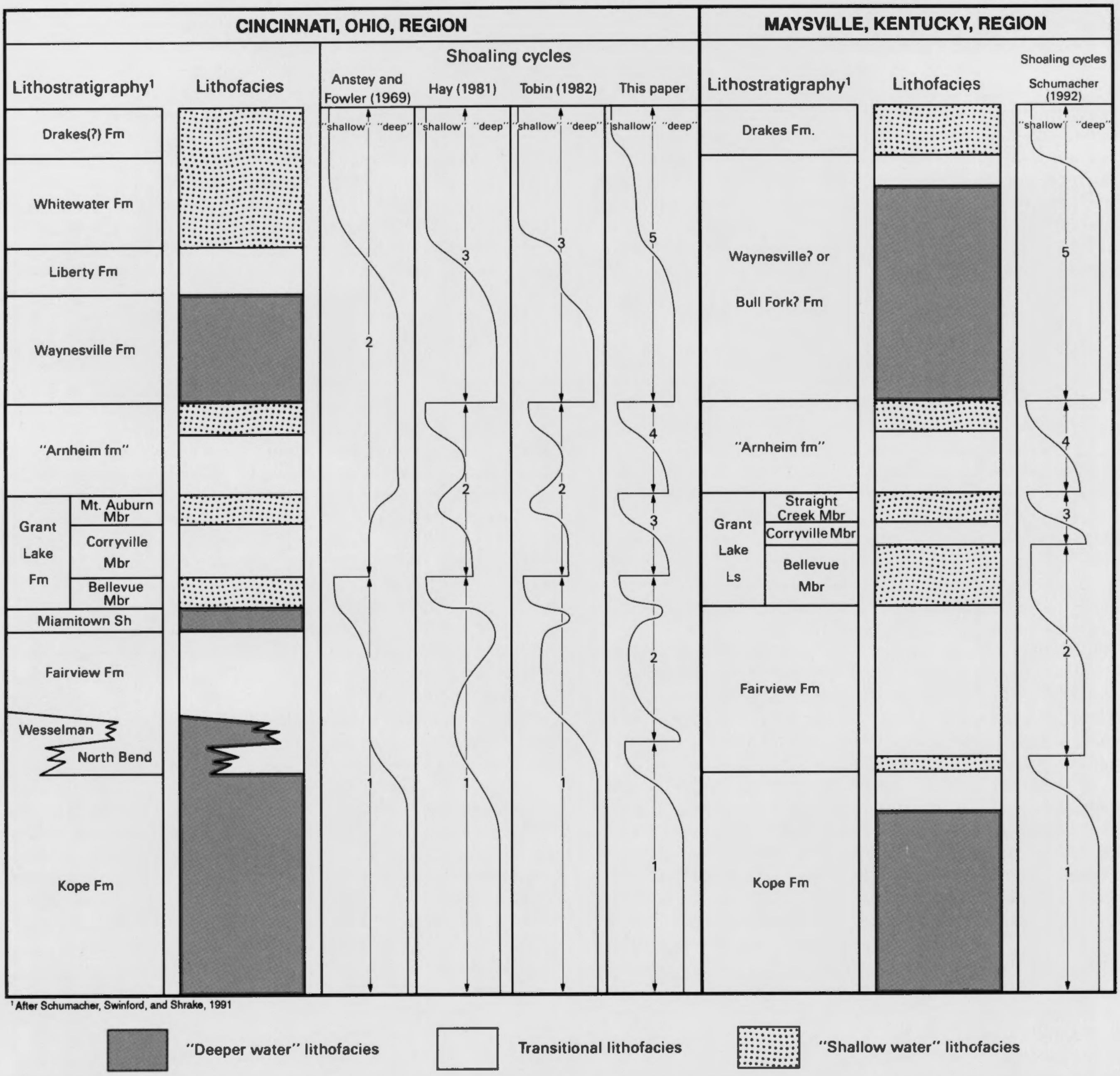


FIGURE 16-4.—Schematic diagram comparing the lithostratigraphy, the lithofacies, and the interpretation of shoaling cycles of the Cincinnatian Series exposed in the Cincinnati, Ohio, and Maysville, Kentucky, regions.

of the Miamitown Shale.

The shale-dominant lithofacies of the Miamitown Shale intertongues with the upper part of the limestone-dominant transitional lithofacies of the Fairview Formation and the lower portion of the limestone-dominant "shallow-water" lithofacies of the Bellevue Member of the Grant Lake Formation in Butler, Hamilton, and Warren Counties and the western portion of Clermont County, Ohio. Ford (1967) and Hay (1981) interpreted the Miamitown Shale as representing a shale-dominant "deeper water" lithofacies. Tobin (1982) believed this unit represents a shale-dominant, "shallow-water" lithofacies. Dattilo (paper 7 in this volume) provides additional information on the interpretation of the lithofacies of the Miamitown Shale.

My experience with the Miamitown Shale is limited to a few exposures mapped in Clermont and Warren Counties. I recognized two discrete tongues of Miamitown Shale and the meter-scale shoaling-upward cycles described by Dattilo (1991). The tongues of Miamitown rapidly pinch out or grade into the Fairview Formation or the Bellevue Member of the Grant Lake Formation. The limits of the Miamitown as a mappable unit have been delineated in parts of Clermont and Warren Counties by Schumacher (1990) and Shrake and Schumacher (1992). I do not know what the depositional setting of the Miamitown Shale is because of my lack of experience with this unit.

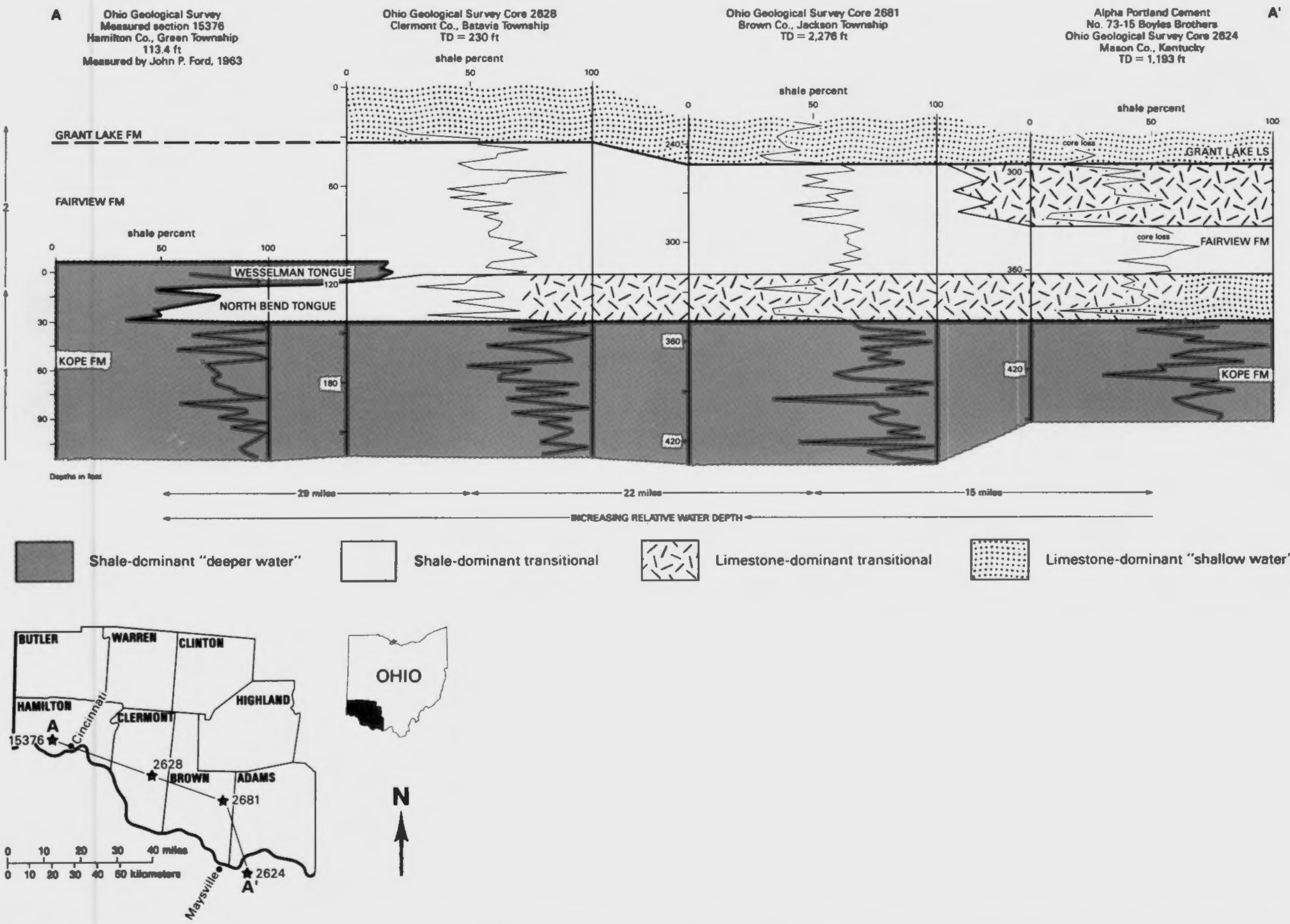


FIGURE 16-5.—Correlation of the upper part of the Kope Formation, the Fairview Formation, and the lower part of the Grant Lake Limestone/Formation between the Cincinnati, Ohio, and the Maysville, Kentucky, regions, illustrating the vertical and lateral changes in lithofacies. The basal two shoaling cycles of the Cincinnatian Series are illustrated by the numbered arrows at the margins of the cross section. Note the lateral gradation of lithofacies in the lower and upper portions of the Fairview Formation.

The third shoaling cycle is from the base of the transitional lithofacies represented by the Corryville Member of the Grant Lake Formation to the top of the Mt. Auburn Member of the Grant Lake Formation. The transitional to "shallow-water" lithofacies of the Mt. Auburn Member is the lateral equivalent of the "shallow-water" lithofacies of the Straight Creek Member of the Grant Lake Limestone.

The fourth cycle ranges from the transitional lithofacies of the lower part of the "Arnheim formation" to the nodular top of the "Arnheim" throughout southwestern Ohio. The fifth shoaling cycle ranges from the base of the "deeper water" lithofacies of the Waynesville Formation to the top of the Cincinnatian Series in southwestern Ohio.

The fifth shoaling cycle is likely an oversimplification of the cyclicity present in the uppermost part of the Cincinnatian Series. The ongoing investigation of the repetitive stratigraphic sequences discovered in the subsurface of west-central Ohio will lead to the recognition of a number of additional shoaling cycles. Presently, I am unsure whether these cycles will be recognized as independent shoaling cycles or as subcycles within the fifth shoaling cycle.

The recognition of intervals characterized by shoaling is beneficial in reconstructing the local geologic setting of the Cincinnatian Series throughout its deposition. Weir and others (1984) and Tobin (1986) suggested the Cincinnatian Series was deposited on a gently northward sloping, mixed siliciclastic-carbonate ramp throughout Cincinnatian time. This depositional setting affected sedimentation throughout much of the sub-Cincinnatian and through the first shoaling cycle in the Cincinnatian Series. In the second and third shoaling cycles, the area of shoaling environments shifted from the Lexington, Kentucky, region to the Maysville, Kentucky, region.

Apparently, as the area of shoaling shifted, so did the direction of the slope of the associated siliciclastic-carbonate ramp. The "deeper water" portion of this ramp was oriented to the northwest, explaining the progressive change from predominantly "shallow-water" lithofacies present in the Maysville, Kentucky, region to the predominantly transitional lithofacies of the Cincinnati, Ohio, region.

The area of shoaling environments shifted from the Maysville, Kentucky, region to the Richmond, Indiana, region in the fifth shoaling cycle. The "shallow-water" lithofacies associated with the Whitewater Formation can be correlated along the outcrop belt of southeastern Indiana into the subsurface of the eastern third of Indiana and portions of west-central Ohio (Gray, 1972; Schumacher, Bergström, and Mitchell, 1991). A mixed siliciclastic-carbonate ramp flanked either side of this north-south-trending shoal, and "deeper water" lithofacies occurred in central Ohio and central Indiana.

Anstey and Fowler (1969), Hay (1981), and Tobin (1982) suggested that shoaling cycles occurred as the result of changes in sea level caused by local or regional tectonics, basin sedimentation patterns, Late Ordovician glaciation, or a combination of these. The exact cause or causes of the shoaling cycles cannot be determined at this time. This uncertainty is the result of the poor understanding of the stratigraphic relationships between the Cincinnati, Ohio, stratigraphic section and coeval sections in the Appalachian Mountains and Midcontinent region. This poor understanding is unfortunate, because recent investigations have refined our understanding of the Taconic Orogeny and its effect on Midcontinent sedimentation (for example, Ettensohn, 1991). The Ohio Division of Geological Survey has correlated surficial Cincinnatian lithostratigraphic units into the subsurface adjacent to the outcrop belt, but more study is needed to bridge the gap between Upper Ordovician outcrops in the Appalachian Mountains and the Midcontinent region.

Tobin (1982) and Jennette and Pryor (1993) have recognized additional sedimentary cycles from the Cincinnatian Series of southwestern Ohio. These cycles, termed megacycles and storm cycles by Tobin (1982) and shallowing-upward bedding cycles and storm beds by Jennette and Pryor (1993), range in thickness from 1 to 3 meters (3.3-9.8 ft) and less than 1 meter (3.3 ft), respectively. Tobin suggested that megacyles were the result of fluctuating sediment supply because of deltaic shifting, changing tectonics, or climatic changes. Jennette and Pryor (1993) believed that shallowing-upward bedding cycles are the result of cyclic fluctuation of sea level caused by glacio-eustacy.

Megacycles, shallowing-upward cycles, and storm cycles have been recognized in the course of our field mapping. The Ohio Division of Geological Survey has not attempted detailed correlation of these cycles. However, a few observations can be stated concerning them. Megacycles and shallowing-upward cycles occur in many of the formations of the Cincinnatian Series, but not everywhere in the abundance in which they occur in the upper portion of the Kope Formation and the lower part of the Fairview Formation. Storm cycles or beds occur in all the lithostratigraphic units of the Cincinnatian Series, and many limestone and shale beds have been produced by or influenced by storm-generated sedimentary processes.

What do the various scales of sedimentary cycles tell us about the formation of the Cincinnatian Series? For over a decade, I have been working to resolve this question. I have not finalized my answer, because detailed subsurface correlation to coeval rocks exposed in the Appalachian Mountains and the Midcontinent region has not been completed. My feeling is that, when these correlations are completed, some shoaling cycles will be traceable between the Cincinnati, Ohio, region and the Appalachian exposures. The recognition of these cycles will allow the interpretation of how the tectonic events associated with the Taconic Orogeny affected sedimentation in the Cincinnatian Series.

With updated regional correlations, my guess is that the Cincinnatian Series will be interpreted as mixed siliciclastic-carbonate sedimentation on at least three gently sloping, storm-dominated ramps. The orientation of these ramps varied through time because of the influence of tectonic pulses associated with the Taconic Orogeny.

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Address of author: Gregory A. Schumacher, Ohio Department of Natural Resources, Division of Geological Survey, 4383 Fountain Square Drive, Columbus, OH 43224-1362.

17. PALEOGEOGRAPHY AND PALEOENVIRONMENTS, FAIRVIEW THROUGH WHITEWATER FORMATIONS (UPPER ORDOVICIAN, SOUTHEASTERN INDIANA AND SOUTHWESTERN OHIO)

by
Helen B. Hay

INTRODUCTION

The focus of this paper is the lithofacies of about 122-168 meters (400-550 ft) of section that includes the upper part of the Kope Formation through the Whitewater Formation to the Ordovician/Silurian contact in southeastern Indiana and southwestern Ohio. The goal is to determine what the stratigraphic and geographic distribution of the facies suggests about the paleogeography, paleoenvironments, and geologic history of the area. The rocks are thin gray limestones composed of whole and broken marine fossils interbedded with compacted, but not cemented, terrigenous clay and silt that are traditionally called shales, although they are more accurately classified as mudstones. Facies intervals differ from each other in the proportion of shale to limestone and in internal and bedding characteristics of both rock types.

Gray (1972) assigned the Upper Ordovician of Indiana to the Maquoketa Group and identified four provinces: a deep basin in the southwest, a western shelf in the northwest, an eastern shelf, and a southeastern shelf. Most of the limestones are in the eastern part of the eastern shelf and in the southeastern shelf, the eastern parts of which include the area of this study. Most of the Cincinnatian of the central and western parts of the state is shale. Weir and Peck (1968) and Cressman (1973) studied the Middle and Upper Ordovician rocks of Kentucky, most of which are shallow-water limestones. So this paper deals with details of an area viewed as shelf from central Indiana and basin from central Kentucky.

In general, these sediments accumulated on a shallow marine shelf at depths that ranged from above normal wave base to, more commonly, near or below storm wave base. The large number of thin facies intervals suggests that the depositional environment was subject to frequent minor changes that would be expected in very shallow seas rather than in the more stable environments of deeper shelves. The regional facies patterns show wedges of >70 percent shale that thicken toward the northwest or northeast. These shale wedges intertongue with limestone-rich zones of <70 percent shale that thicken first toward the south then, later in the Cincinnatian, along a more nearly north-south axis. Most of the contacts between units are gradational and, therefore, are believed to be time transgressive. The characteristics of the lithofacies, as well as their stratigraphic relationships based on isopach maps, leads to a reasonable interpretation of depositional environments, paleogeography, and transgressive/regressive cycles.

Localities included in the study are shown in figure 17-1 and are listed at the end of this paper. Hay (1981) described the geographically named localities, five of which are cores: New Point, Wayne County, Randolph County, Miamisburg, and Middletown. Descriptions of part of the Brookville composite section and of some other localities were published by Hay and others (1981), and a portion of the Madison composite section by Totten and Hay (1987). The numbered localities (1-22) are mostly from Kentucky GQ maps. Information from open-file core descriptions provided by the Ohio Division of Geological Survey (2627 in Warren County; 2537,

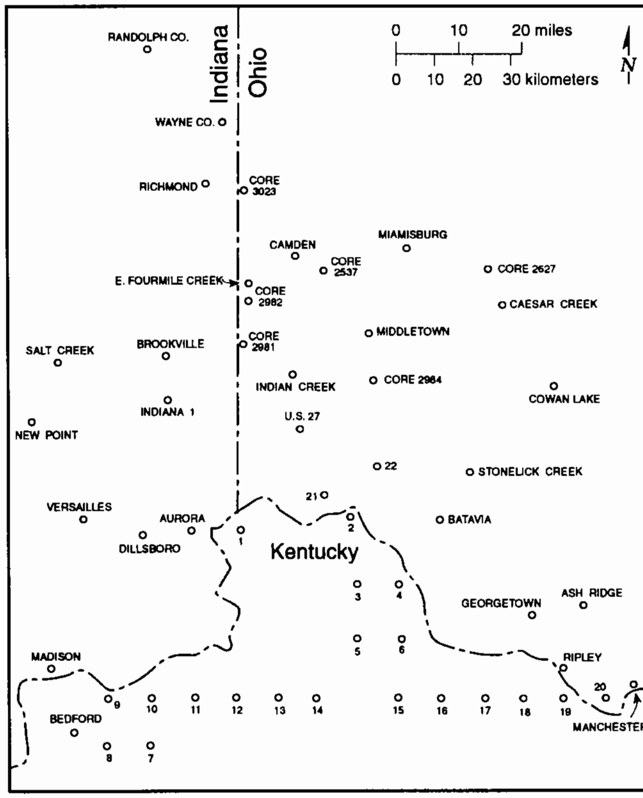

FIGURE 17-1.—Index map (modified from Hay, 1981). Localities marked "core" are cores of the Ohio Division of Geological Survey. For references for numbered localities (1-22) see Localities on p. 132-133.

2981, 2982, and 2984 in Butler County; and 3023 in Preble County) are incorporated, to the extent possible, in this discussion. Several localities are described in other papers in this volume: the Indiana Route 1 road cut at South Gate Hill (IN-FR-0005; paper 12 in this volume); the Madison, Indiana, road cuts (IN-JE-0001, IN-JE-0002, and IN-JE-0003; paper 6); the Brookville Dam spillway (IN-FR-0002; paper 8); Bon Well Hill (IN-FR-0001; paper 10); Garr Hill/ Brookville North (IN-FR-0003; paper 11); and the U.S. Route 27 road cut near Richmond, Indiana (IN-WY-0001; paper 15).

LITHOFACIES AND STRATIGRAPHY

LITHOFACIES CLASSIFICATION

The lithofacies classification that underpins this discussion was developed through detailed study of the Brookville and Richmond composite sections (Hay, 1975), then modified and applied regionally (Hay, 1981). It is a field classification that has proven effective in describing both outcrops and cores. The key characteristics of the lithofacies are summarized in figure 17-2. There are four facies groups. Groups 1, 2, and 3 are distinguished on the basis of the shale percentage in an interval: >70 percent, 55-70 percent, and <55

Principal diagnostic characteristics of lithofacies		
Group 1 >70% shale	1a	Well-bedded, mostly thin limestones and medium to thick, fissile to blocky shales. Includes massive units of 100% shale. Low-diversity fauna.
	1b	Rubbly, shaly, nodular limestones; medium to thick shales with limy stringers and layers of fossils in shale matrix. May have some well-bedded limestones as in 1a. Low-diversity fauna. Most easily seen in cores.
Group 2 55-70% shale	2a	Like 1a except has high diversity of fauna. Intermediate in shale percentage between 1a and 3a.
	2b	Well-bedded limestones, rubbly nodular limestones, and limy shales. Allochems tend to be more finely broken than 2a. High-diversity fauna. Intermediate between 3a and 3c.
Group 3 <55% shale	3a	Well-bedded, thin to medium limestones and thin to medium, fissile to blocky shales. High-diversity fauna.
	3b	Well-bedded, thin to medium limestones with or without rubbly or nodular shales. High-diversity fauna. Intermediate between 3a and 3c.
	3c	Thin-bedded, rubbly weathering, argillaceous limestones, very thin limy shales. High-diversity fauna.
	3d	Limestones and shales as in 3a except >20% of limestones are fine-grained laminated burrowed, barren of large fossils; trails on tops. Grade to siltstones.
Group 4 Miscellaneous	4a	High-angle cross-bedded calcarenites, bimodal dip. Little or no shale.
	4b	Granule-size fossils in thick to massive beds; little or no shale. May be like 4a if seen in similar outcrops.
	4c	Massive *Loxoplocus* limestone bed. Marble Hill Bed.
	4d	Bioturbated light-gray limestone with low-diversity fauna of ostracodes, algae, snails, and *Tetradium*. Related to Saluda facies complex.

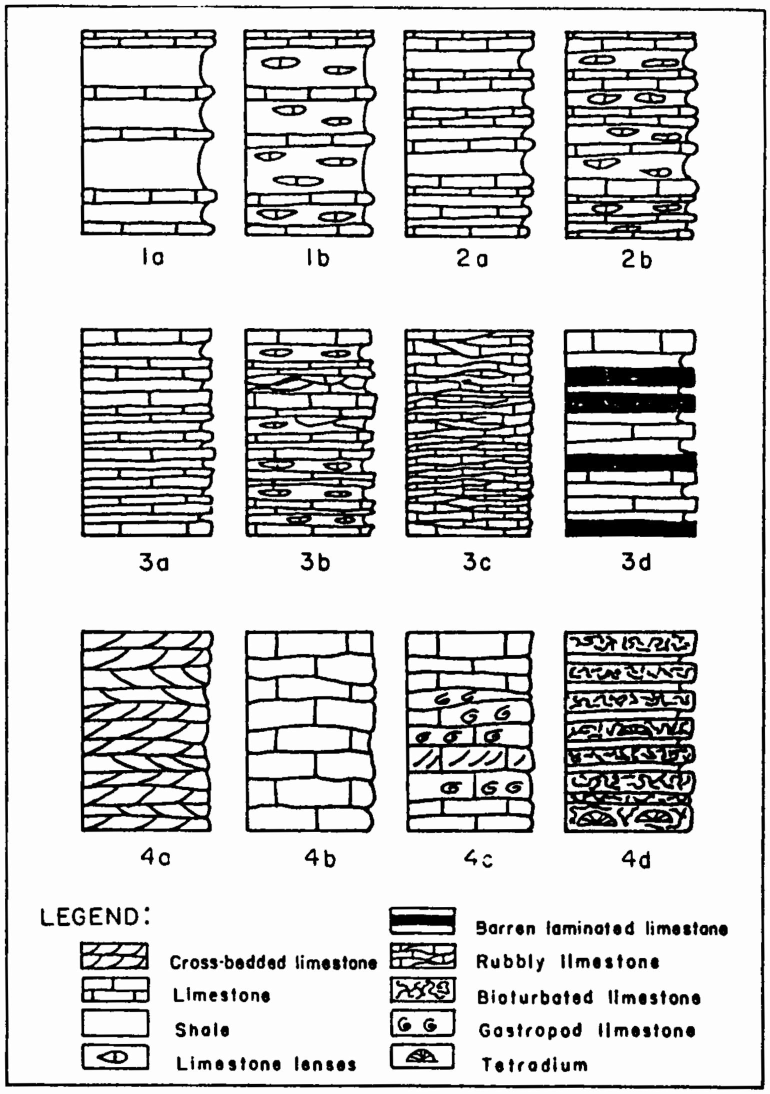

FIGURE 17-2.—Principal diagnostic characteristics of lithofacies and illustration of lithofacies types. Modified from Hay (1981) and Hay and others (1981).

percent, respectively. Within these three groups the letter designations are based on the nature of the shales and limestones. The letter "a" indicates a predominance of planar rather than nodular or rubbly limestones and shales that are predominantly free of calcareous stringers, lenses, or nodules. The "b" facies have calcareous stringers, lenses, or nodules in the majority of the shales. Group 3 (<55 percent shale) has two additional facies: 3c, containing nodular, rubbly limestones and limy shales, and 3d, containing planar limestones, >20 percent of which are laminated, burrowed, and composed of silt- and fine-sand-sized allochems. The latter facies appears to be unfossiliferous in hand specimen or outcrop. The facies of group 4 are much less common but are useful environmental indicators where they occur. The classification is open ended in that all four groups can be expanded, if the need arises.

FORMATIONS AND MEMBERS

Regional correlation of lithofacies (Hay, 1981, pls. 1 and 2) suggests a reasonable division of the Cincinnatian Series into formations and members (Hay 1981, pl. 3) that is somewhat different from that currently in use in Indiana and Ohio (fig. 17-3). The Indiana Geological Survey recognizes four formations: the Kope, Dillsboro, Saluda, and Whitewater Formations. The Ohio Division of Geological Survey recognizes the Kope and Fairview Formations, Miamitown Shale, Grant Lake Formation (divided into the Bellevue, Corryville, and Mt. Auburn Members by Schumacher, Swinford, and Shrake, 1991), the Arnheim formation (informal), the Waynesville, Liberty, and Whitewater Formations, and the Elkhorn shale (informal). In south-central Ohio, the Ohio Survey recognizes the Drakes Formation at the top of the Ordovician.

My suggestion, presented here informally, incorporates some of the units of Ohio and Indiana, but, in some respects, is different from either. It is illustrated schematically along a south-north cross section in figure 17-4. The Kope (facies 1a), Fairview (facies 2a and 3a), Miamitown (facies 1a), and Bellevue (facies 3b and 3c) can be traced throughout the area and should be retained in Ohio and recognized in Indiana. The Bellevue lithology is similar to that of the Whitewater

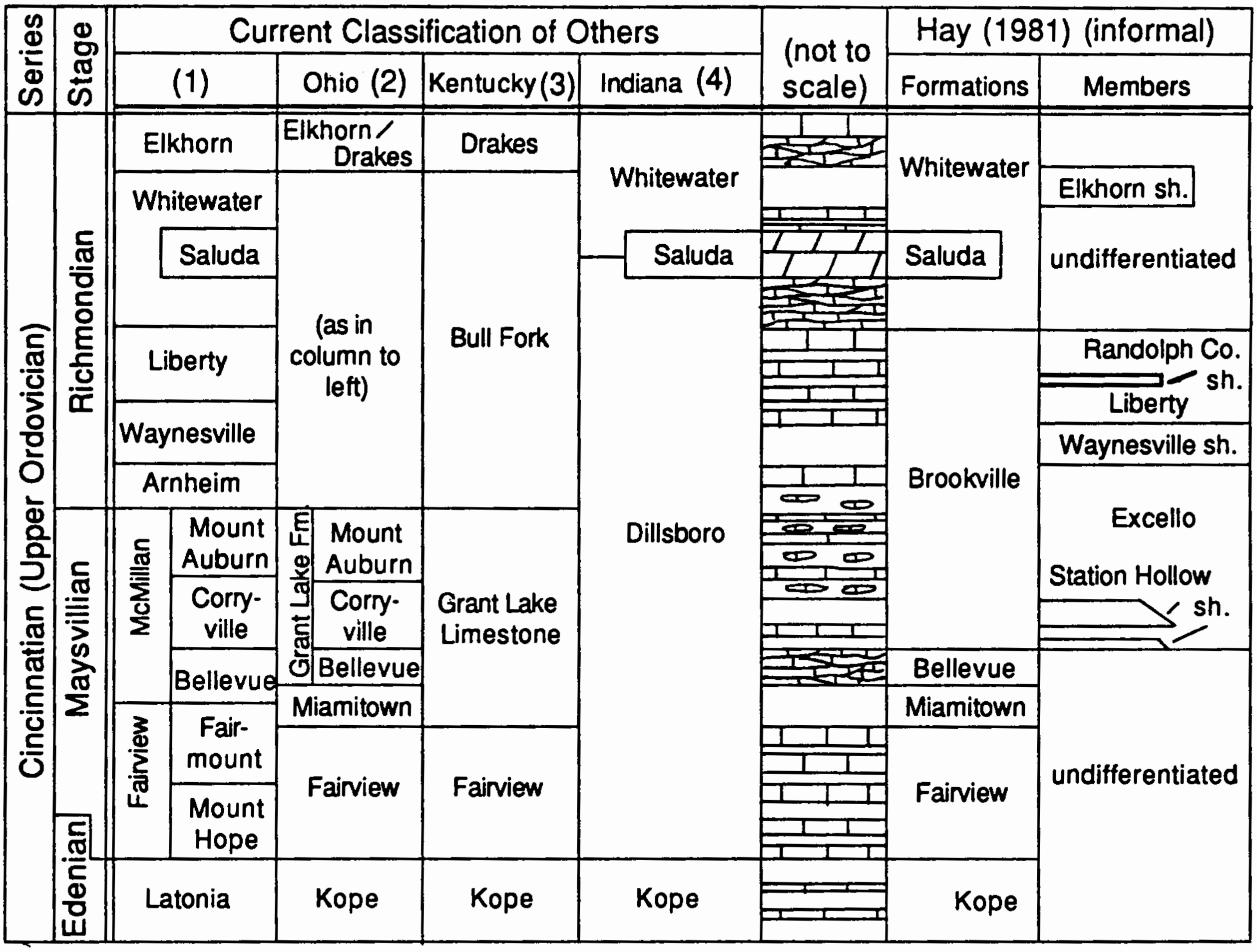

FIGURE 17-3.—Rock-stratigraphic classification (modified from Hay, 1981, and Hay and others, 1981). In the "current classification of others," (1) = Caster and others (1955) and Davis (1992). (2) = Kope from Weiss and Sweet (1964); Fairview and Miamitown from Ford (1967); Grant Lake Formation and members upward from Schumacher and others (1991). (3) = Peck (1966). (4) = Brown and Lineback (1966) and Gray (1972).

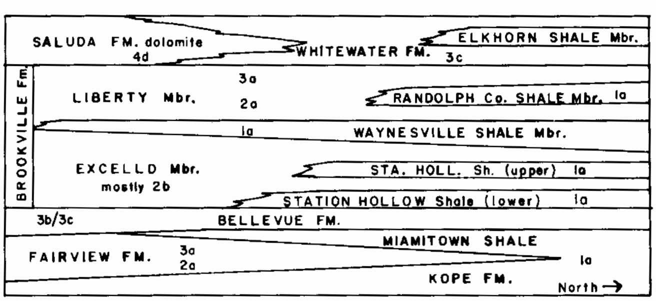

FIGURE 17-4.—Generalized south-north distribution of formations and members as identified in this paper. The Bellevue Formation of the diagram is the Bellevue Member of the Grant Lake Formation as used by Schumacher and others (1991). Modified from Hay (1981) and Hay and others (1981).

(facies 3b and/or 3c), and I suggest recognition of a new formation, the "Brookville formation," for the interval of variable lithology between the Bellevue and the Whitewater or the Saluda, whichever is lower in a given section. The "Brookville formation" can be divided into facies intervals that could be considered members or tongues: the "Excello member," the Waynesville Shale Member, the Liberty Member and the "Randolph County Shale member." Within the "Excello" there are two shale tongues (>70 percent shale) called the "Station Hollow shales." In 1981 I believed these shale tongues merged in the vicinity of the Miamisburg core and therefore called them tongues of the same unit. In view of new information in nearby cores, I now think these are two separate shale wedges and should not be made a single member of the "Brookville formation," although they should be identified in the description of cores and outcrops because of what they can show about sedimentation patterns in the area. The "Station Hollow shales" are at least in part equivalent to the Corryville Member of the Grant Lake Formation in Ohio. The "Excello" includes the Corryville and Mt. Auburn Members of the Grant Lake Formation and the Arnheim formation of Ohio nomenclature. The "Excello" consists of a variety of facies, mostly of groups 2 (55-70 percent shale) but including some group 3 (<55 percent shale), and mostly in "b" or "c" divisions (limy shales and/or rubbly limestones). Overall, the greatest volume of the "Excello" is facies 2b.

The Waynesville-Liberty interval is characterized by decreasing shale percentage upward. On the basis of the descriptions of their cores, the Ohio Division of Geological Survey seems to put the contact approximately where the shale percentage drops below 55 percent, which correlates with my boundary between facies 2a and 3a. I prefer to place the Waynesville-Liberty contact lower in the section so that the Liberty includes facies of Group 2, mainly 2a, as well as 3a, and limits the Waynesville to the predominantly 1a facies. This placement seems reasonable in view of the fact that the Liberty, as here defined, includes the same facies sequence as the lithologically similar Fairview Formation, facies 2a overlain by 3a. This placement makes the Waynesville Shale Member comparable in facies to the Miamitown and "Station Hollow shales" wedges that underlie and overlie the Bellevue, respectively. Unfortunately, at the present time, I do not know where this 70 percent-shale boundary occurs in the Ohio cores, so I cannot relate the Waynesville-Liberty boundary in those cores to its placement based on the 70 percent-shale criterion. Within the Waynesville Shale Member, as defined here, there is a thin but widespread interval of facies 2a or 3a. It would also be useful to know where this interval falls within the Ohio cores, because it constitutes a useful datum for regional correlation.

In the Randolph County and Wayne County cores, and possibly in the Miamisburg core, a tongue of facies 1a (>70 percent shale) within the Liberty has been called the "Randolph County Shale member." Inspection of the Ohio Survey cores, particularly those in the north, should make it possible to identify this shale tongue. It probably is within the upper part of their Waynesville Formation.

In summary, the "Brookville formation" consists of shale wedges—the "Station Hollow shales" in the "Excello member," the Waynesville Shale Member, and the "Randolph County shale member—that lie between the intervals of lower clastic ratio, the "Excello" and Liberty Members. Most of the "Excello" and the Liberty consist of facies in groups 2 and 3. The "Excello member" generally has limy shales and some rubbly limestones of facies 2b and, less commonly, 3b or 3c. The Liberty Member is predominantly facies 2a in the lower part and 3a in the upper part, a decrease in shale upward. The "Excello member" differs from the Bellevue and Whitewater Formations in that most of it is within the 55-70 percent shale range, whereas the Bellevue and the Whitewater have much less shale, placing them in facies of group 3 (3b and/or 3c). This facies division of the "Brookville formation" is useful because it identifies shale tongues and facies sequences that are significant in understanding the geologic history of the area. Finally, the Elkhorn Shale member, a tongue of facies 1a within the Whitewater Formation, is informally proposed as a member of the Whitewater Formation. In Preble County (Ohio) core 3023, the Elkhorn Shale was identified as an informal unit above the Whitewater, with undifferentiated Upper Ordovician strata above it. The nearby Richmond outcrops (see paper 15 in this volume) and the Wayne County core contain Whitewater rubbly lithology (cemented with dolomite) as well as some other facies above the Elkhorn Shale member, so it seems reasonable to extend the Whitewater Formation to the top of the Ordovician, at least in this area.

DEPOSITIONAL ENVIRONMENTS OF LITHOFACIES

Interpretation of depositional environments depends on the characteristics of individual facies and on their stratigraphic relations as revealed in transition and probability matrix analysis (Hay, 1981). The matrix analysis gave the probability that each facies would be overlain by each other facies and compared that result with the probabilities if the facies sequence were random. This was done for one-step transitions and for reversible two-step transitions, for example, 1a overlain by 2a overlain by 1a. The geological significance of facies successions that are in conformable vertical contact is that they represent adjacent depositional environments (Walther's Principle; Blatt and others, 1972, p. 187-188). The environmental conditions responsible for some facies are relatively easy to interpret on the basis of individual facies characteristics. For others, the evidence is less clear, and intepretation must rely heavily on the association of these facies with those that are less ambiguous. This discussion of facies associations and environments is followed in the next section by isopach maps of formations and members. The combined information makes it possible to interpret paleogeography and history of these Cincinnatian rocks.

INTERPRETATIONS OF FACIES OF GROUPS 3 AND 4

Figure 17-5 shows schematically the suggested lateral relations of the lithofacies based on facies associations and characteristics. The facies for which environmental interpretations are least ambiguous are those of group 4, all of

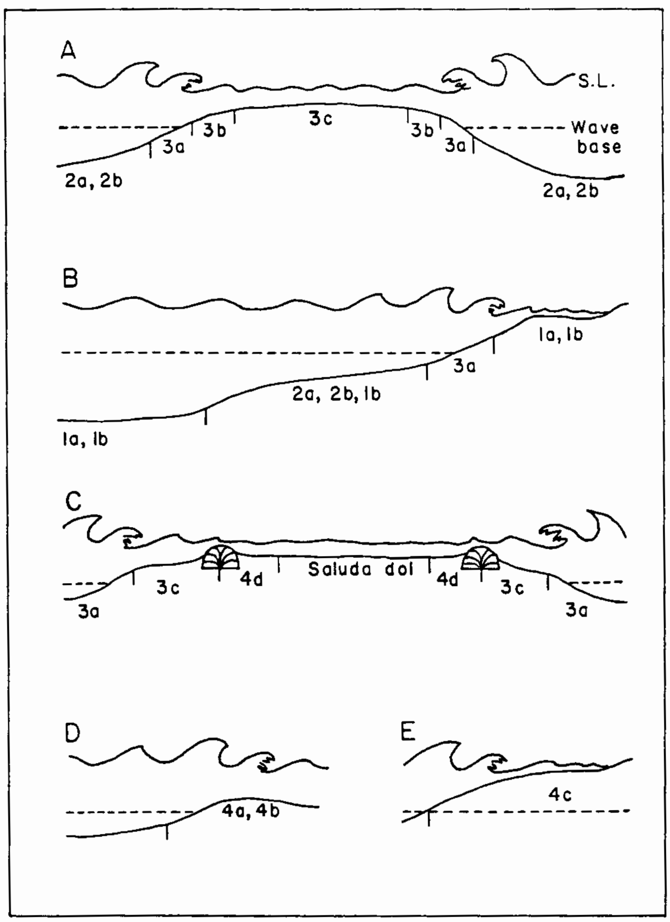

FIGURE 17-5.—Possible depositional environments and lateral relations of facies. From Hay (1981) and Hay and others (1981). Fan-shaped symbol in diagram C represents *Tetradium* colonies. Approximate lateral scale for diagrams A, B, and C is tens of miles; for diagrams D and E, a few hundred or a few thousand feet. S.L. = sea level; Saluda dol = Saluda Formation; 1a, 1b, 2a, etc. are lithofacies types diagnosed and illustrated in figure 17-2.

which probably indicate very shallow water. Facies 4d is the most significant of these because it is widespread and allows interpretation of the strongly associated facies in group 3, particularly 3c, the rubbly rock of the Whitewater Formation. Facies 4d, exposed at Garr Hill (IN-FR-0003; see paper 11 in this volume) near the top of the Brookville composite section about 4 miles (6.4 km) north of Brookville, Indiana, is a thoroughly burrowed, micritic limestone with very little shale. It contains algae in which the structure is preserved and a fauna of ostracodes and small snails but lacks the normal marine fauna of bryozoans, brachiopods, and echinoderms characteristic of most of the Cincinnatian. It is underlain by massive *Tetradium* colonies that are a part of the Saluda Formation described by Hatfield (1968). Farther south and west in Indiana, facies 4d is overlain by Saluda dolomite containing mud cracks. Hatfield (1968) thought that the *Tetradium* masses ringed and acted as a wave baffle for a shallow and intermittently exposed lagoon in which the dolomite formed. The stratigraphic position and fossil characteristics of facies 4d suggest that it formed in quiet, very shallow, probably somewhat hypersaline water just lagoonward of the baffle. The Garr Hill outcrop is near the northern margin of the Saluda, and no dolomite occurs there (Hay and others, 1981). Facies 4d is overlain by, and in some cases interbedded with, facies 3c, the rubbly Whitewater; therefore, facies 3c must have formed in a laterally adjacent environment (fig. 17-5C) that was only slightly deeper, but, as the diverse fauna indicates, the water was of normal marine salinity.

Although formed in shallow water, facies 3c probably was deposited under relatively low energy conditions compared to 3b and 3a, with which it is stratigraphically associated. Both its field characteristics and limestone thin sections support this interpretation. Of the limestones studied, 60 percent of the facies 3c thin sections are micritic compared with 26 percent for facies 3a, and 71 percent of the facies 3c limestones are rudites compared with 50 percent for facies 3a. With the exception of the horn corals, which may be biochemically eroded, the fossils of facies 3c are not significantly abraded, brachiopods are commonly articulated, and molluscan steinkerns are abundant. These factors are consistent with a relatively quiet environment, as is the poor separation of the fine clastics and carbonates into discrete beds. Such conditions could occur on the interior of a shallow platform as illustrated in figure 17-5A. Marginal to this platform, under higher energy conditions, facies 3b and 3a could have formed as illustrated. This distribution is analogous to the facies distribution of the Bahama Bank (Imbrie and Purdy, 1962), where higher energy environments are marginal to the bank.

The major facies of the Bellevue is facies 3b, which has thin planar or wavy carbonate beds separated by thin fossiliferous shales and rubbly limestones. The Bellevue environment, although similar to that of the Whitewater facies 3c, was shallow but more strongly agitated, at least when the sediments of the more laterally continuous, less rubbly limestone beds were deposited.

Facies 3a, which has planar limestones and blocky or fissile, relatively unfossiliferous shales, is characteristic of the upper part of the Fairview and Liberty. This facies probably was deposited below normal wave base but periodically was subjected to agitation by storm waves and strong currents that separated the coarser biogenic debris from the fine clastics, thereby producing the limestone beds, and at least the lower part of the overlying shale, as current velocity decreased.

The concept of storms as a mechanism for producing the interbedded limestones and shales of the Cincinnatian is supported by the fact that the lower bedding surfaces of the limestone beds commonly are in sharp contact with the underlying shales, but the tops of the beds are commonly silty or gradational with the overlying shales. The siltstone beds that commonly are interbedded with shales (for example, in the Fairview and the lowest part of the Waynesville) also are likely to be the result of storms that sorted the silts rather than biogenic debris from the muddy sediments. Surely these thin siltstones are best explained as the result of localized mechanical separation of the coarser grains of the muds and not by periodic influx of silt from a distant source area. There is no evidence that individual siltstone layers thicken in any particular direction or can be traced to any source area. Therefore, the siltstones and at least many of the limestones have a similar origin. In addition, the broad lateral extent of the limestone beds compared to their thinness strongly suggests that storms played an important role in their final characteristics and burial by spreading into thin sheets any localized biogenic buildups.

Meyer and others (1981) described another possible way in which storms may have influenced the sediments. Terrigenous clastics suspended by storms may have been carried to nearby localities and deposited on top of the shelly substrate and living organisms without producing any significant reworking of the carbonate debris. The characteristics of the limestone beds in this case would depend on whether the biogenic material had been reworked prior to the event that buried it.

INTERPRETATION OF FACIES GROUPS AND THE SHALE PROBLEM

A major problem or ambiguity in facies interpretation arises when one considers the cause of changes in clastic ratios that distinguishes groups 1, 2, and 3. A change in clastic ratio can be caused by a change in the sedimentation rate of terrigenous clastics, by a change in the rate of production of carbonates, or by both. The sedimentation rate of clastics can be a function either of rate of supply from the source area or of hydrodynamic conditions in the basin. The rate of biogenic-limestone production can be influenced by water depth, substrate texture (softness), turbidity, or variation in chemical conditions such as salinity or Eh, all of which may affect the density and diversity of carbonate-producing organisms.

The question of interpretation is complicated further by uncertainty about the conditions under which muds are deposited. The traditional view for shales, such as those in the Cincinnatian of Ohio and Indiana that were deposited tens to hundreds of miles from land, is that sedimentation of the muds took place under relatively low energy conditions. Pryor's (1975) work on modern muds suggests that flocculation and biogenic pelletization may cause the clays and silts to behave more like sand particles. If this idea applies to the Ordovician shales, then there may have been very little difference in the energy levels responsible for the shales and the sand-sized allochems that are common constituents of the limestones.

Another traditional view about the shale-rich intervals such as the Miamitown Shale, the Waynesville Shale Member, and the Elkhorn Shale member is that they were deposited at greater depth than the enclosing limestone-rich intervals. This view probably is true for some of the Cincinnatian shales but not for all. Each of these shale tongues needs to be interpreted individually. A facies sequence of 1a, 2a, and 3a upward such as the Kope through the Fairview, or the 2a to 3a transition upward in the Liberty, probably indicates shoaling-upward conditions. The fact that the Kope is quite uniform and thick over a large geographic area suggests a stable, relatively deep water environment. The limestone content increases near the top of the Kope where it grades into the Fairview, probably as a consequence of progressive shoaling. Figure 17-5B illustrates this interpretation of lateral relations of these facies as well as an alternative environment of very shallow water for facies 1a.

When facies 1a or 1b is in direct contact with those of group 3, it may not be appropriate to attribute the facies change to an abrupt change in water depth. The Elkhorn Shale member may be an example of this situation in which an influx of clastics, or a difference in water chemistry, rather than a change in water depth, is a more reasonable explanation for the facies change.

I believe that the contact between the Waynesville Shale Member and the "Excello member" is a disconformity; if so, the Waynesville Shale Member, at least in the lower part, probably was deposited in very shallow water. In most localities the contact between the "Excello" and the Waynesville is sharp and involves an abrupt lithologic change. The upper part of the "Excello" is nodular or rubbly limestones and limy shales of facies 1b or 2b. In many localities these facies are overlain by a few feet of facies 3a with brown, sandy-textured, friable sediment between fairly well sorted limestone beds. These brown beds owe their texture to sand-sized, phosphatized steinkerns of minute brachiopods, mollusks, and other small fossils. This band of facies 3a is commonly oxidized, even in cores; this oxidation suggests it may be the top of the regressive phase of the "Excello" and lies just below the disconformity. On the other hand, this 3a band may be the basal unit of a transgressive Waynesville cycle. The basal beds of the Waynesville are facies 1a shales with interbeds of siltstone, rather than limestone, and very few fossils. The Waynesville Shale Member becomes more fossiliferous upward. To the north, in the Randolph County, Wayne County, and Preble County (3023) cores, the contact is somewhat less sharp, but throughout the region this contact is the most consistently abrupt lithologic change in the Cincinnatian. Cumings and Galloway (1913) noted an abrupt faunal change at this contact, where about 30 species of bryozoans either disappear or appear; this faunal change, they said, is greater than at any other stratigraphic horizon in the Cincinnatian. The proper assignment of the 3a zone that I placed at the top of the "Excello" probably could be determined by a study of the bryozoans within it. So the interpretation of a disconformity is supported both by faunal and lithologic evidence, although the precise position of the disconformity is not certain.

If the barren shales and siltstones at the base of the Waynesville represent the basal beds of a transgression, then the sediments must have been deposited in very shallow water unless the transgression was extremely rapid. Unlike the Kope, this occurrence of facies 1a would not be a deep-water deposit. The scarcity of fossils may be due to abnormal water chemistry or a high rate of mud sedimentation that created turbid or otherwise unstable conditions, possibly an unusually soft, soupy substrate. As the transgression proceeded, water depth increased, as did the biological diversity. The gradual increase in fossil diversity and abundance argues against a rapid transgression and deposition of the Waynesville sediments in deep water. Linguloid brachiopods are common in the lower part of the Waynesville, and their presence also suggests a shallow-water environment (Hay and others, 1981).

The fauna of the upper part of the Waynesville Shale Member (as limited here to facies 1a) has characteristics in common with the upper part of the Kope (Hay and others, 1981) and may have formed at similar depth, although this is not the only possible explanation for the similarity of the fossil assemblages. They both may have been controlled by turbidity or substrate texture rather than depth. The fine clastics of the Waynesville shales may have been derived from weathering and erosion of a low landmass exposed during the hiatus as well as from source areas to the east and southeast, the likely source of most of the Cincinnatian terrigenous clastics. The disconformity may not exist in the northern cores where the contact is somewhat less abrupt than elsewhere. This contact is well exposed near the base of both the new Indiana Route 1 road cut at South Gate Hill (IN-FR-0005) and Bon Well Hill (IN-FR-0001) (see papers 10 and 12 in this volume).

In summary, the facies with >70 percent shale, those of group 1, may have formed in a variety of environments. The difference between facies 1a and 1b, which has more limy shales and/or nodular rubbly limestones, may be in the degree of effectiveness of storms in segregating the biogenic debris from the finer clastics; if so, facies 1a would have resulted when sorting was effectively accomplished. Facies 2b, for example, in the upper part of the "Excello," is quite similar to facies 3c of the Whitewater except that it contains more shale. It may be that the supply of clastics was greater when the "Excello" sediments accumulated.

REGIONAL ISOPACH AND STRUCTURE-CONTOUR MAPS

Isopach and structure-contour maps (figs. 17-6 through 17-8) show a tentative regional picture that is very likely to be revised as more information from the Ohio Division of Geological Survey is incorporated. To the extent possible based on available descriptions, these maps include information from Ohio Survey cores 2537 (D. A. Stith and E. M. Swinford, written and oral commun., 1983, 1991), 2627 (Shrake and others, 1990), 2981, 2982, 2984, and 3023. There are problems in attempting to incorporate information from these new cores that relate to illustration of isopachs for intertonguing facies and a lack of information on placement of boundaries for units within the "Brookville formation."

The structure-contour map for the base of the Fairview Formation (fig. 17-6B) shows patterns similar to those of the base and top of the "Brookville formation" (Hay, 1981) that reflect post-Ordovician deformation.

ISOPACH MAPS OF THE FAIRVIEW, MIAMITOWN, AND BELLEVUE

Figures 17-6C, 17-6D, and 17-7A are isopach maps for the Fairview Formation, the Miamitown Shale, and the

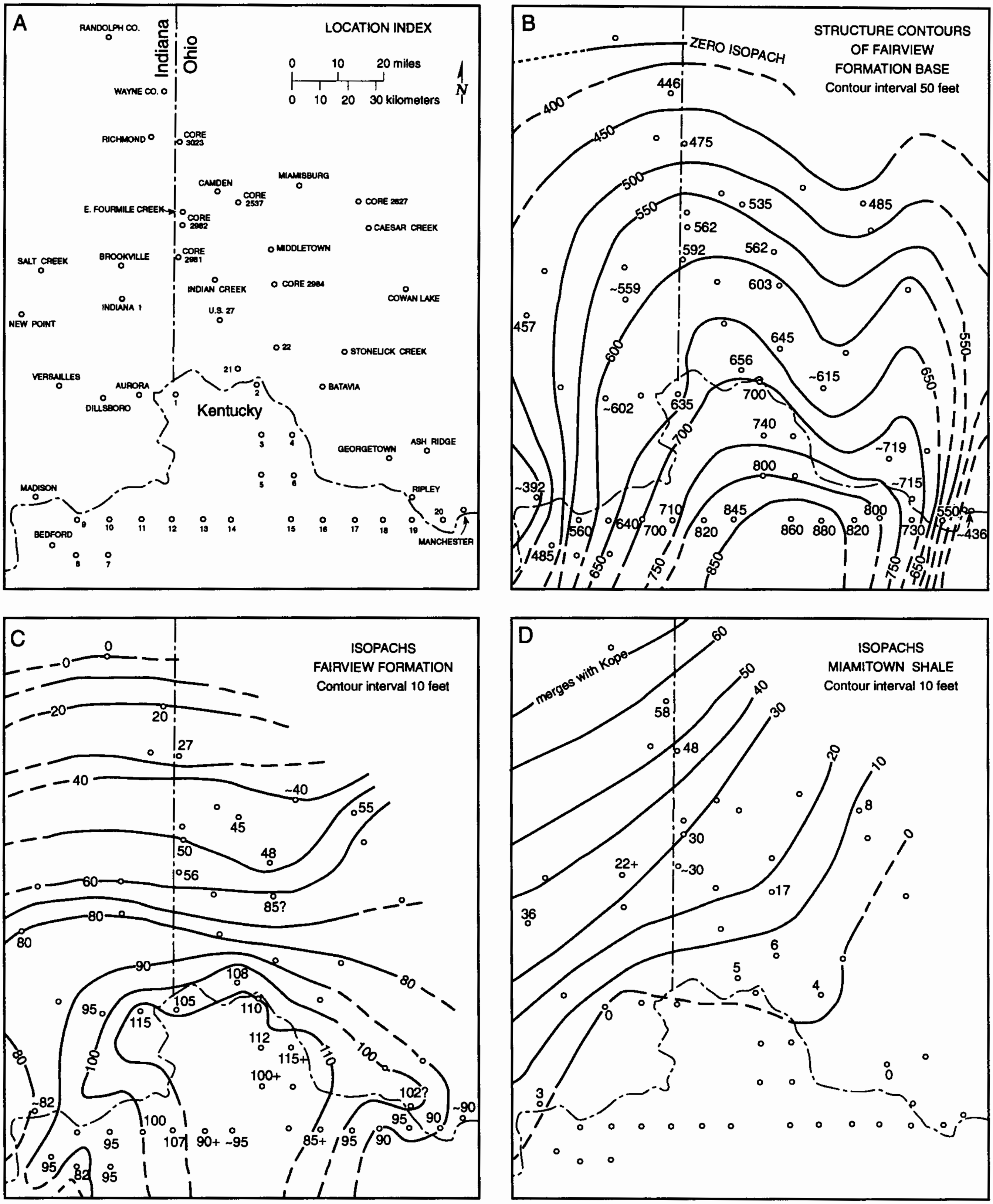

FIGURE 17-6.—Index map (A), structure and isopach maps of the Fairview Formation (B, C), and isopach map of the Miamitown Shale (D). Modified from Hay (1981). The value (85?) for core 2984 on C is plotted but not contoured.

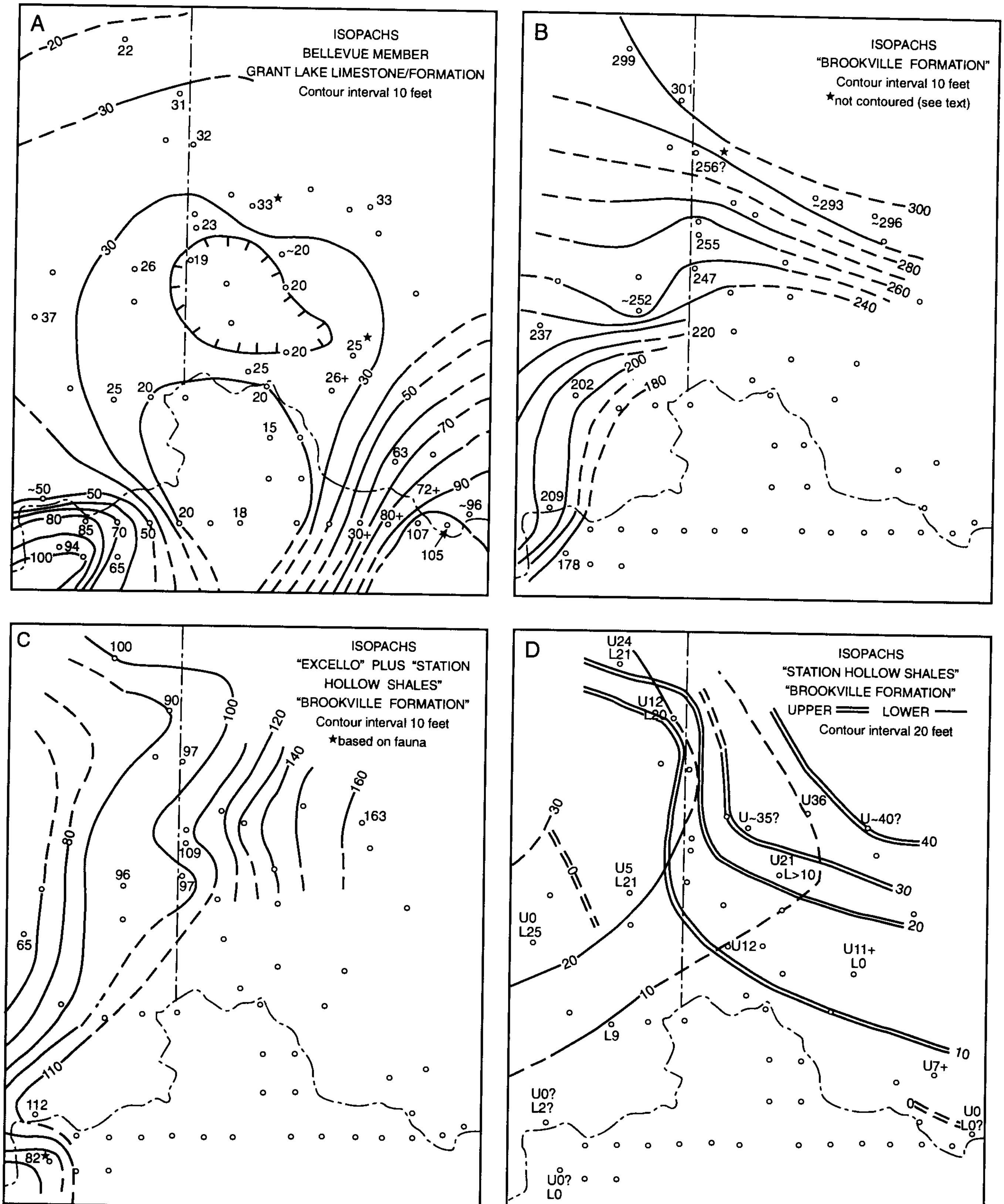

FIGURE 17-7.—Isopach maps of the Bellevue Member of the Grant Lake Limestone/Formation (A), the "Brookville formation" (B), the "Excello member" plus "Station Hollow shales" wedges (C), and the "Station Hollow shales" wedges (D). Modified from Hay (1981). For Ohio cores, thicknesses of the "Excello member" are obtained from the sum of the Grant Lake and the Arnheim Formations, minus the Bellevue Member.

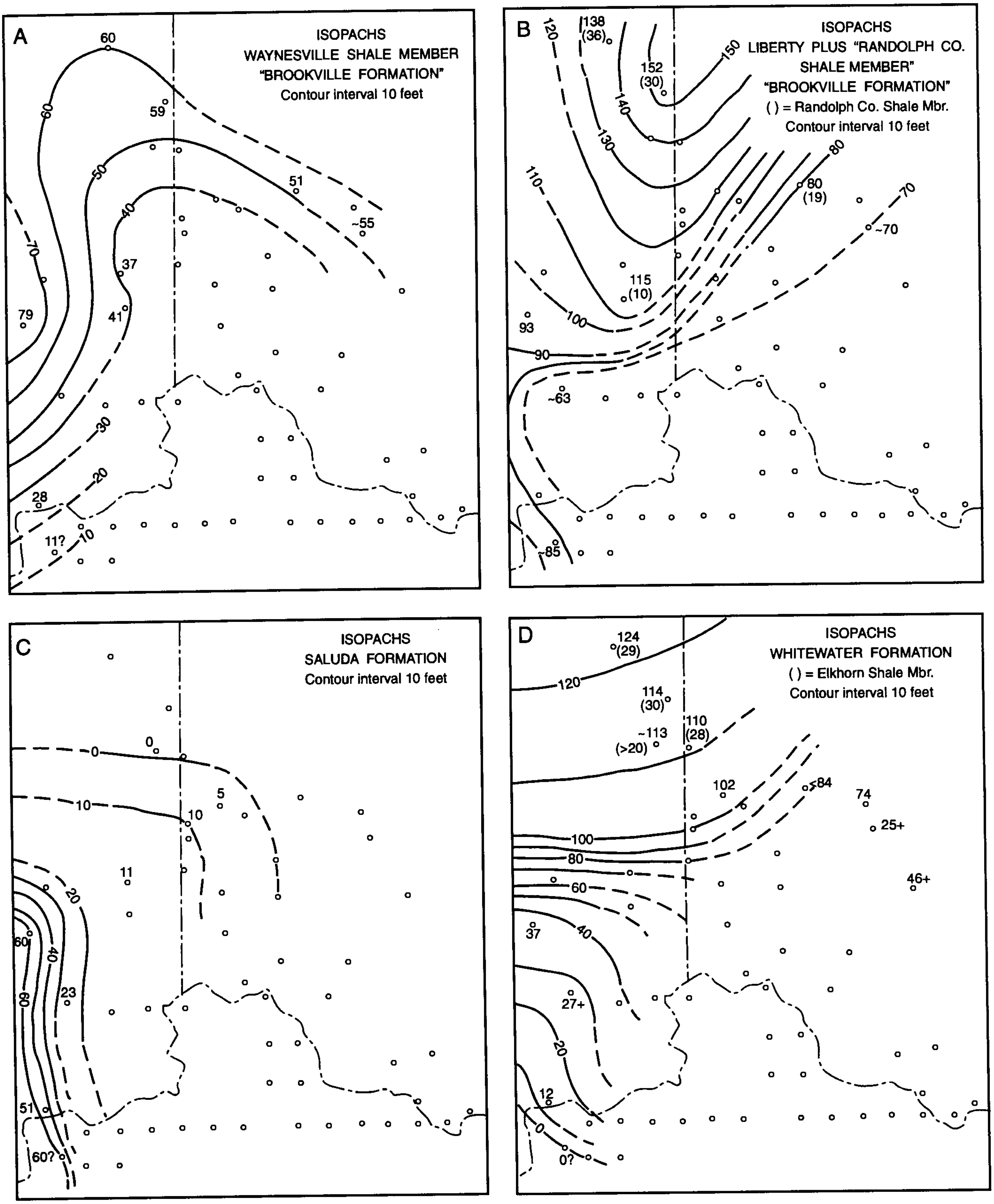

FIGURE 17-8.—Isopach maps of the Waynesville Shale Member (A), the Liberty Member plus the "Randolph County Shale member" (B), the Saluda Formation (C), and the Whitewater Formation (D). Modified from Hay (1981).

Bellevue Member of the Grant Lake Formation, respectively. Intertonguing of these units has been described in cores 2981 and 3023. For core 2981, the tongues of Fairview and Bellevue lithology within the Miamitown Shale were added to the Fairview Formation and the Bellevue Member, respectively, in making the isopach maps (figs. 17-6C and 17-7A), and the remainder was included in the Miamitown Shale (fig. 17-6D). For core 3023, the lowest 27.0 ft (8.2 meters) of Fairview lithology are put in the Fairview Formation, and the uppermost 5 ft (1.5 meters) of Fairview lithology are included in the Bellevue, which immediately overlies it and has a lower shale percentage than the Miamitown. Even including the two tongues of Fairview lithology within the Miamitown, the interval, overall, probably is still above the 70 percent shale boundary characteristic of the Miamitown elsewhere. Another problem in the Fairview isopach map (fig. 17-6C) is the thickness of 85 ft (25.9 meters) of Fairview in core 2984 compared to only 48 ft (14.6 meters) about 7 miles (11 km) to the northwest in the Middletown core (Hay, 1981) and about 70 ft (21 meters) approximately 10 miles (16 km) south in northern Hamilton County (Osborne, 1970, 1974). This apparent change in thickness may be a consequence of where the boundaries of the Fairview are placed, rather than a true stratigraphic difference. The value for core 2984 is shown on the Fairview isopach map but is not contoured.

The Fairview Formation thins toward the north and pinches out between the Wayne County and Randolph County cores (fig. 17-6C) where the Kope and the Miamitown merge. Ford (1967) commented on the steeper northward slope indicated by the structure contours on the top of the Fairview compared to the base; he thought this slope indicated a northward-sloping sea floor in the vicinity of Cincinnati. This pattern continues northward from Cincinnati; the base of the Fairview from Bellevue Hill in Cincinnati (OH-HA-0003, no. 21 on fig. 17-6A) to the Wayne County core decreases in elevation by 210 ft (64.0 meters) (fig. 17-6B), but the top of the Fairview between those localities drops 299 ft (91.1 meters). This difference is consistent with Ford's interpretation of a north-sloping ramp. The Fairview also thins somewhat toward the southeast and southwest and reaches a maximum thickness in north-central Kentucky. The base of the Fairview is probably younger toward the north.

The articulate brachiopod *Strophomena planoconvexa* occurs in the middle of the Fairview (60 ft/18.3 meters above the base) at Bedford, Kentucky, in about the middle of the formation in Cincinnati (J. K. Pope, oral commun., 1980), and probably in the middle at Aurora, Indiana, but at the base at Ripley, Ohio. The occurrence of this fossil seems to be limited to a thin stratigraphic interval and, thus, may represent a timeline; if so, then its lower position at Ripley compared with the localities farther west means that the base of the Fairview is younger at Ripley.

The Miamitown Shale (fig. 17-6D) thickens toward the northwest in the direction of the Maquoketa Shale basin that occupied much of Indiana during this part of the Cincinnatian (Gray, 1972). The Miamitown isopachs are not perfectly complementary to those of the Fairview, although the two units clearly are related. The Miamitown appears to be time transgressive from the northwest toward the southeast, so that it was being deposited in the north at the same time as the upper part of the Fairview farther south. At least the lower part of the Miamitown probably represents a return to the slightly deeper water conditions of the Kope, indicating a relatively greater subsidence of the shelf toward the northwest.

The Bellevue isopach map (fig. 17-7A) show an entirely different pattern, thick toward the southeast and southwest and thinner but of relatively uniform thickness elsewhere, implying relatively uniform depositional conditions for the Bellevue on a shallow platform. The complementary thicknesses of the Fairview and the Bellevue in the southwest and southeast may imply that the Fairview and Bellevue are partly time equivalent. So the environments of the Fairview, Miamitown, and Bellevue may have existed simultaneously in different parts of the basin. Meyer and others (1981) reached this same conclusion.

The facies sequences and isopachs together suggest this history: shoaling in the upper part of the Kope as the limestone content increases, and continuing through the Fairview, beginning in the south or southwest and progressing northward and eastward. Then followed subsidence and a return to a deeper water environment in the northwest that resulted in the lower part of the Miamitown Shale. The Bellevue lithology (facies 3b and 3c) indicates very shallow conditions. The upper part of the Miamitown may record a rather rapid shoaling that ended the northwestward and northward sloping of the sea floor while the Bellevue sediments accumulated on a shallow platform of fairly uniform depth. In the south, if the upper part of the Fairview is time equivalent to the lower part of the Bellevue in the southeast and southwest, and if the Fairview represents deeper water than the Bellevue, then there appear to have been shoals (Bellevue) in the southwest and southeast with a deeper channel (Fairview) between them. Furthermore, both the Fairview and the Bellevue could be partly time correlative with the Miamitown farther north.

ISOPACH MAPS OF THE "BROOKVILLE FORMATION"

Isopach maps of the "Brookville formation" and its members, the interval between the top of the Bellevue and the base of the Whitewater or the Saluda Formation, are shown in figures 17-7B through 17-8B. Unlike the Fairview Formation that thins northward, the "Brookville formation" is more nearly uniform in thickness but thickens toward the north and northeast. In the south-central part of the area the original thickness cannot be determined due to post-Ordovician erosion. The north-south trend of the isopachs of the "Brookville formation" in the southwest is complementary to the thickening of the Saluda Formation in that direction (fig. 17-8C).

In Indiana, if the thickness of the shaly intervals of the "Brookville formation" is subtracted from the total thickness, the trend of the isopachs changes from east-west to nearly north-south (just slightly northeast-southwest), and the unit thins westward. For example, the "Brookville formation," without the shales, thins by 50 ft (15.2 meters) between Brookville and New Point. So the northward thickening of the "Brookville formation" as a whole in Indiana (fig. 17-7B) is due to greater thickness of the shales, not to an increase in thickness of the limestone-rich intervals. Not enough information is available for Ohio to be sure what happens there.

Preble County (Ohio) core 3023 has a described thickness of only 256 ft (78.0 meters) between the top of the Bellevue and the base of the Whitewater (the "Brookville formation") compared with 301 ft (91.7 meters) just 10 miles (16 km) northwest in the Wayne County core. The Whitewater Formation (including everything above the "Brookville formation") for core 3023 is 61 ft (18.6 meters) thicker than in outcrops near Richmond only 2 or 3 miles (3-5 km) away. So, in core 3023, the "Brookville formation" is thinner than expected, and the Whitewater is thicker than expected. These discrepancies are caused either by a difference in the placement of the "Brookville"/Whitewater boundary or there is a significant facies change over a very short distance. Thickness for this core is not contoured on the Brookville isopach map.

The "Excello member" and the "Station Hollow shales" wedges within it include the interval from the top of the Bellevue to the top of the Arnheim of Ohio nomenclature. The "Excello" isopachs (fig. 17-7C) indicate thickening toward the east and are consistent with the trend shown by Schumacher and others (1991, fig. 4C) for the Corryville Member of the Grant Lake Formation and the Grant Lake Formation as a whole in Butler and Warren Counties.

Isopachs of the "Station Hollow shales" also are plotted separately in figure 17-7D. At the present time these shale wedges have not been identified in the Ohio cores, although approximations of thicknesses are interpreted for two of the cores, 2537 (D. A. Stith and E. M. Swinford, oral and written commun., 1983, 1991) and 2627 (Shrake and others, 1990). The lower "Station Hollow shale" wedge has the same general trend as does the Miamitown, thickening toward the northwest, and is likely the result of subsidence in the northwest and a return to deeper water conditions. On the other hand, the thickening of the upper tongue toward the northeast may be the result of an increased supply of clastic sediments rather than a deepening of the sea, in view of the fact that the entire "Excello member" also thickens in that direction. This shale seems to produce a net addition of sediment to the section; it is not accompanied by thinning of the limestone-rich portions of the "Excello."

The depositional strike of isopachs for the Waynesville Shale Member in Indiana is generally northeast-southwest; the unit thickens toward the west and northwest (fig. 17-8A). There are not enough data points for confidence in the trends in Ohio at the present time, although it will be possible to get this information from the Ohio cores to clarify both this and the Liberty map (fig. 17-8B). The two points that are mapped in Ohio suggest that the Waynesville may thicken toward the northeast as well as the northwest. This wrap-around pattern, if real, suggests that the Cincinnati Arch, or a nonstructural shoal, was present and may be related to the probable disconformity at the top of the "Excello." If the Waynesville is transgressive across a disconformity, its base should be older and its thickness greater in the direction from which the transgression came, from the northwest and northeast. It would thin toward the axis of the arch, where sedimentation began later. This pattern for the Waynesville Shale Member also may suggest that the arch was present.

Isopachs for the Liberty Member plus the "Randolph County shale member" have a roughly north-south axis; the units thin toward the west and east and thicken toward the north (fig. 17-8B). The northward thickening is modified if the thickness of the "Randolph County shale member," shown in parentheses on this map, is subtracted, but the overall pattern does not change significantly. There are not enough data points for the "Randolph County shale member" to tell whether it thickens toward the northwest, north, or northeast; new data from Ohio, when incorporated, should clarify this trend. The Liberty Member thins in the southwest owing to early onset of the conditions that produced the Saluda Formation and terminated the environment in which the Liberty formed.

ISOPACH MAPS OF THE WHITEWATER AND SALUDA FORMATIONS

The Saluda isopachs (fig. 17-8C) indicate that the Saluda Formation does not extend as far north as Richmond, although there are Saluda facies in western Butler County, Ohio. The description of Ohio core 2981 makes no mention of Saluda, but the top of the core is within the Whitewater Formation and may be below any Saluda occurrence there. Perhaps it is more likely that facies 4d, by which the Saluda is identified in that area, was not recognized in the core. This reasoning seems likely in view of the fact that 50 ft (15.2 meters) of Whitewater are described in the core, but nearby, at Camden, there are only 21 ft (6.4 meters) of Whitewater below the Saluda, and only 18 ft (5.5 meters) below it along East Fourmile Creek.

The Whitewater Formation (fig. 17-8D) is preserved only around the margins of the outcrop area and in cores in areas where it has been protected from erosion by a cover of Silurian rock. Even where protected, it is possible, or likely, that erosion between the times of deposition of the Ordovician and Silurian rocks in this area removed some of the original latest Ordovician rock. The thinning of the Whitewater in the southwest is complementary to the thickening of the Saluda there. In the north, part of the thickness of the Whitewater Formation is the Elkhorn Shale member, which is 29 ft (8.8 meters) thick in Randolph County, 30 ft (9.1 meters) thick in Wayne County, and 28 ft (8.5 meters) thick in Preble County core 3023. On the basis of only these three points, the Elkhorn Shale member may thicken toward the northeast. Farther southeast in Ohio, at Manchester, for example, the unit at the top of the Ordovician is the shale-rich Drakes Formation, which is underlain by the Bull Fork Formation. In core 2627 in Warren County, Ohio, 74 ft (25.6 meters) of Whitewater is overlain by more than 42 ft (12.9 meters) of dolomitic, silty shale assigned to the Drakes Formation. The stratigraphic relationship between the Drakes Formation in the southeast and the Elkhorn Shale Member to the north is not clear.

SUMMARY AND OVERALL INTERPRETATION OF THE ISOPACH MAPS

Inspection of these isopach maps as a series suggests that the Cincinnati Arch, or at least a north-south-trending shoal, may have developed during the Cincinnatian Epoch. Of the limestone-rich units, only the Fairview Formation and the Saluda Formation thin to the north. The Bellevue, except in the southwest and southeast corners where it is quite thick, maintains a relatively uniform thickness and may mark the change from a north-sloping sea floor to a more uniform shoal. The "Excello" is thicker toward the northeast, and the Liberty is thicker northward and thins both toward the northwest and the northeast. The Whitewater thins southward, possibly owing to pre-Silurian as well as post-Silurian erosion; in the southwest the thinning of the Whitewater is complementary to the thickening of the Saluda.

The shale-rich intervals thicken toward the northwest, the northeast, or both. The Miamitown and the lower "Station Hollow shale" wedge thicken northwestward, but the upper "Station Hollow shale" wedge thickens toward the northeast. The Waynesville Shale Member possibly thickens toward both the northwest and the northeast. The "Randolph County shale member" may thicken toward the north, the northwest, or the northeast. The Elkhorn Shale Member may thicken toward the northeast, although this trend is based on only a few data points.

The intervals with lobate contours include both shale-rich and limestone-rich units: the "Station Hollow shales," the Waynesville, the Liberty/"Randolph County," and the Saluda. All of these units have a roughly north-south-trending axis. It seems possible that this axis is caused by a north-south-trending shoal that replaced a northward slope of the sea floor that existed during deposition of the Fairview sediments. As discussed earlier, the Bellevue platform may indicate the beginning of this shoal, which became more pronounced in the lower half of the "Brookville formation," where shales thin toward the axis. This interpretation is consistent with the likely disconformity at the top of the "Excello" and its relation to the lobate isopachs of the overlying Waynesville Shale Member. This tentative interpretation is subject to confirmation or revision when the data from the Ohio Division of Geological Survey are incorporated.

SEDIMENTARY CYCLES

Figure 17-9 presents an interpretation of sedimentary cycles within the Cincinnatian based on the facies sequences and isopach maps; the three localities depicted are Bedford, Kentucky (in the southwest), Manchester, Ohio (in the southeast), and the Wayne County, Indiana, core (in the north). Although the details are somewhat different, the interpretation of all three localities is that there are three major regressive phases separated by two transgressive phases and some minor oscillations within them. The datum is the middle of the Grant Lake Formation or the Bellevue Formation. The positions of possible index fossils *Holtedahlina*, *Strophomena concordensis*, and *Strophomena planoconvexa*, and the peak zone of *Thaerodonta* are marked.

Others have recognized cycles in the Cincinnatian. For example, Weir and Peck (1968) concluded that the facies of the Grant Lake (Bellevue) indicated shallower conditions than those of the underlying Fairview, and that at least two regressive phases were evident. Fox (1962) thought the Whitewater and Saluda sediments were deposited in a more shallow sea than the underlying Tanners Creek Formation (upper part of the "Excello member" and the Waynesville Shale and Liberty Members of the "Brookville formation"). If there is a disconformity between the "Excello" and the Waynesville Shale Member, then there must have been a third transgression at the time of deposition of the Waynesville sediments; maximum depths probably are represented by facies 2a of the Liberty (fig. 17-9, Wayne County). The South Gate Hill locality paper in this volume (Hay, Kirchner, and Cuffey, paper 12) describes these cycles from the "Excello" to the Saluda Formation. The graph of Wayne County also illustrates a transgression to explain the Miamitown Shale. Hay (1981) discussed this figure in more detail.

In summary, there appear to be three regressive phases, the first and third culminating in the similar shallow-water facies of the Grant Lake/Bellevue and the Whitewater and Saluda Formations, and the second at the top of the "Excello member" of the "Brookville formation." The transgressive peak in the second cycle is within the "Excello member," within the "Station Hollow shales," or both. The peak in the third cycle may not have been synchronous through-

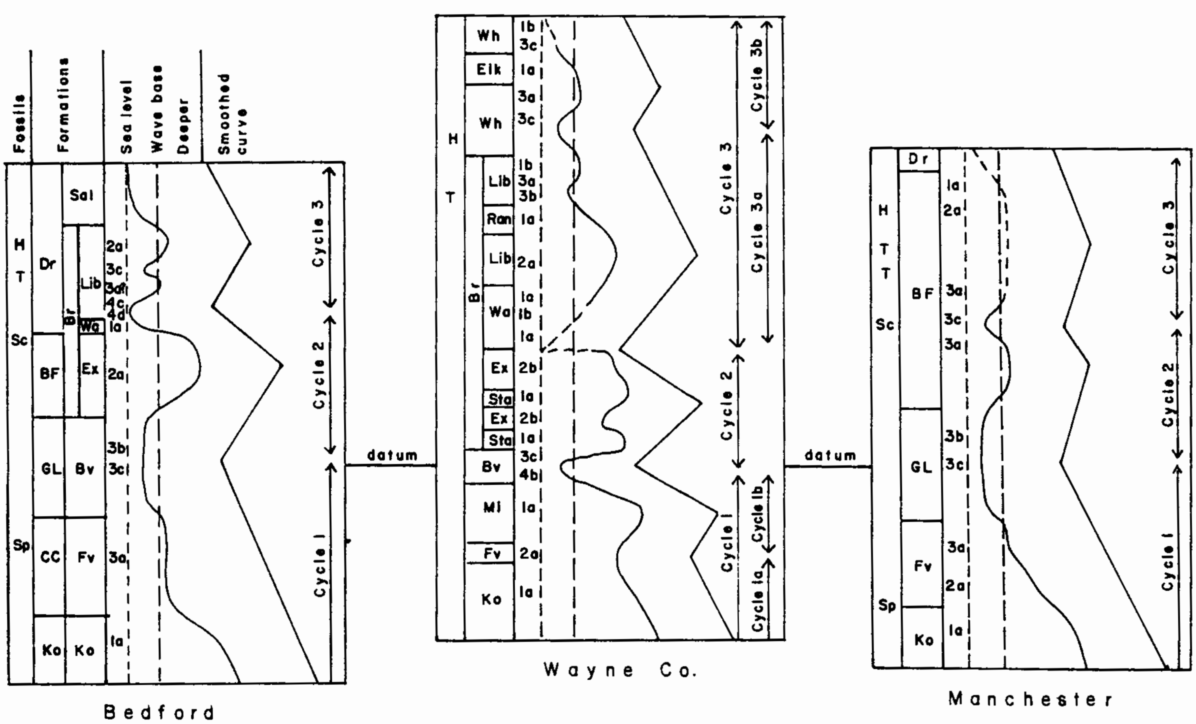

FIGURE 17-9.—Transgressive and regressive cycles for the Bedford, Kentucky, Wayne County, Indiana, and Manchester, Ohio, sections. Fossils: H = *Holtedahlina*, T = *Thaerodonta*, Sc = *Strophomena concordensis*, Sp = *S. planoconvexa*. From Hay (1981).

out the region, although it is everywhere below the Whitewater and Saluda. Minor oscillations are indicated by the facies sequences, the most notable of which is the transgression that resulted in the Miamitown Shale and interrupted the major regression of the first cycle in the north.

This discussion would not be complete without considering the possibility that what appear to be transgressions and regressions in the sense of changing water depths due either to eustatic fluctuation or to differential rates of subsidence in fact may have been caused by pulses of clastic influx or progradation of clastics from the east resulting in shale wedges, separated by times of lower clastic supply in which the more limestone-rich strata were deposited. In fact, the presence or absence of carbonate sediments on modern tropical shelves seems to depend more on the supply or lack of supply of clastics rather than on small variations in water depth.

Although there may have been some such pulses of clastic influx, the nature of the depositional environments of the least ambiguous facies, those of the Bellevue, the Whitewater, and the Saluda Formations, argues in favor of cyclic changes in water depth. Compared with the Fairview Formation and the Liberty Member of the "Brookville formation," these formations were deposited in very shallow seas, so the interpretation of changing water depths seems valid. Facies 2a and 3a of the Fairview and "Liberty" have characteristics other than shale percentage that distinguish them from the Saluda, Whitewater, and Bellevue and lead to the interpretation of somewhat deeper water for these sediments.

Another possibility is that some of the shoaling could have been caused by an influx of clastics that partially filled the basin and thereby caused the depth to decrease. In view of the fact that the Miamitown Shale directly underlies or intertongues with the shallow-water Bellevue, at least the upper part of the Miamitown may represent such an influx. But the Miamitown thickens toward the northwest and the only known source of terrigenous clastics is to the east or southeast, so the Miamitown is not thicker in the direction of any known source. Sediment by-passing is a possibility. Similarly, the Elkhorn Shale member may have been produced by increased influx of clastics based on its association with the shallow-water facies of the Whitewater Formation.

A possible approach to the problem of rate of supply of muds, which bears on interpretation of changes in clastic ratios, will be available when there are time markers in which we can have confidence. The total stratigraphic thickness between timelines could be determined for different localities. If subtraction of the shale-rich intervals (facies 1a/1b) decreases the difference in total thickness for different localities, one might reasonably conclude that the shale zone was caused by a net increase in siliciclastic sedimentation rather than inhibition of carbonate-producing organisms. The thicker stratigraphic intervals between timelines would occur in those localities that also had more shale. In view of the abundance and quality of preservation of macroscopic fossils, it seems likely that modern biostratigraphic work, as well as review of the older paleontological literature, should yield good index fossils.

The cause of these transgressions and regressions may be epeirogenic, either limited to this geographic region or related to tectonism in the Appalachians, or it may be glacioeustatic (Berry and Boucot, 1973), or both. If it is glacioeustatic, then there should be widespread evidence of the cycles in shallow marine sediments of other parts of the stable craton.

RELATION TO APPALACHIAN TECTONISM

It is widely accepted that the source of the clastic sediments of the Midwest was Late Ordovician erosion of tectonic highlands in the Appalachian belt (Dott and Batten, 1988). The result was formation of a clastic wedge which was deposited in a linear trough or foreland basin that was parallel to the orogenic belt and that prograded westward. Bretsky (1970) illustrated a westward migration of increasingly coarser clastics through Maysvillian and Richmondian time. This migration should have produced an increase in terrigenous clastics upward through the Cincinnatian in southeastern Indiana and southwestern Ohio. In fact, that is the case near Manchester, Ohio, the easternmost locality of this study. There (fig. 17-9), the Grant Lake Limestone is succeeded by the Bull Fork Formation, which increases in shale upward beginning at the time of, or just after, deposition of the Waynesville Shale Member farther northwest. The Drakes Formation at the top of the Ordovician at Manchester, Ohio, contains very little limestone.

But just the opposite lithologic change occurs to the west, where the upper part of the "Brookville formation" and the overlying Whitewater and Saluda Formations generally contain less shale upward. This is not what we should expect unless a shoal, possibly the Cincinnati Arch, already existed marginal to the eastern basin. Such a shoal would have helped trap sediments derived from the east in the linear trough of the basin, which thus would have prevented transport onto the shoal on which carbonates could have been forming. The result would be the observed increase in limestone relative to shale upward. The north-south-trending arch or a nonstructural shoal could be an isostatic bulge at the distal margin of the migrating foreland basin (Quinlan and Beaumont, 1984). Therefore, the change to a roughly north-south axial orientation of isopachs noted in some of the units above the Bellevue may be related to tectonism in the Appalachians and development of the clastic wedge of the foreland basin. This speculative model should be tested eventually by examining deep cores or geophysical logs from localities in Ohio east of the area of this study.

LOCALITIES

REFERENCES FOR NUMBERED LOCALITIES IN FIGURE 17-1:

1. Swadley, 1972a, Lawrenceburg, Aurora, Hooven, GQ-989
2. Gibbons, 1973, Newport, Withamsville, GQ-1072
3. Gibbons, 1971, Alexandria, GQ-926
4. Gibbons and others, 1975, New Richmond, GQ-1228
5. Luft, 1970, De Mossville, GQ-862
6. Luft, 1972a, Butler, GQ-982
7. Gibbons, 1975, Worthville, GQ-1265
8. Swadley and Gibbons, 1976, Campbellsburg, GQ-1354
9. Swadley, 1976, Carrollton, GQ-1281
10. Swadley, 1973a, Vevay South, Vevay North, GQ-1123
11. Swadley, 1973b, Sanders, GQ-1095
12. Swadley, 1974, Glencoe, GQ-1154
13. Swadley, 1972b, Elliston, GQ-994
14. Luft, 1973, Williamstown, GQ-1104

15. Luft, 1972b, Falmouth, GQ-1037
16. Luft, 1975, Berlin, GQ-1256
17. Outerbridge, 1971a, Brooksville, GQ-905
18. Outerbridge, 1971b, Germantown, GQ-971
19. Gibbons and Weiss, 1972, Maysville West, GQ-1005
20. Weiss and others, 1972, Maysville East, GQ-1006
21. Ford, 1967
22. Osborne, 1968

NAMED LOCALITIES:

For details of localities followed by numbers in parentheses, see Appendix A at the end of this volume.

Aurora, Indiana (IN-D-0001).

Bedford, Kentucky. Series of road cuts along U.S. Route 42 about 2½ miles (4 km) east of Bedford and along a side road about 1 mile (1.6 km) east of the U.S. Route 42 outcrops (turn northwest on side road). NE rectangle, Bedford, Kentucky, 7.5-minute quadrangle, Trimble County, Kentucky.

Bon Well Hill (IN-FR-0001).

Brookville Dam spillway (IN-FR-0002). The described section extends from the top of the dam down to river level.

Garr Hill (Brookville North) (IN-FR-0003). Described section is on north side of the valley.

Madison, Indiana (IN-JE-0001, IN-JE-0002, IN-JE-0003). The base of the south cut is in the Bellevue Formation and the top of the north cut is Silurian.

Manchester, Ohio (in part OH-AD-0003). Road cuts along Ohio Route 136 from Manchester north to junction with Ohio Route 41.

Miamisburg, Ohio, core. From Mound Laboratory, SE corner, near Miamisburg, Ohio, 7.5-minute quadrangle; core stored at Miami University, Oxford, Ohio.

Middletown, Ohio, core. From SW¼ sec. 19, Trenton, Ohio, 7.5-minute quadrangle; core stored at Miami University, Oxford, Ohio.

New Point, Indiana, core (Indiana Geological Survey drill hole 124). Sec. 8, T. 10 N., R. 11 E., New Point, Indiana, 7.5-minute quadrangle; uppermost Ordovician is exposed in quarry at New Point.

Randolph County, Indiana, core. NW¼NW¼ sec. 16, T. 19 N., R. 13 E., Carlos, Indiana, 7.5-minute quadrangle; core stored at Ball State University, Muncie, Indiana.

Richmond/U.S. Route 27 (IN-WY-0001). See paper 15 in this volume.

Ripley, Ohio (see OH-BR-0008). Road cut about 3 miles (9.8 km) northeast of Ripley on U.S. Routes 62 and 68, SC rectangle, Russellville, Ohio–Kentucky, 7.5-minute quadrangle; the Fairview Formation is exposed just to east on Chicken Hollow Road (see OH-BR-0001) in road cut and along creek about ¼ mile (0.4 km) from U.S. Routes 62/68.

South Gate Hill (Indiana Route 1) (IN-FR-0005). See paper 12 in this volume.

Wayne County, Indiana, core (Indiana Geological Survey drill hole 57). Sec. 12, T. 14 N., R. 1 W., Whitewater, Indiana–Ohio, 7.5-minute quadrangle.

OHIO DIVISION OF GEOLOGICAL SURVEY CORES:

Core 2537. NW¼SE¼NW¼SE¼ sec. 5, T. 3 N., R. 3 E., West Elkton, Ohio, 7.5-minute quadrangle, Wayne Township, Butler County, Ohio.

Core 2627. NE¼ sec. 14, T. 3 N., R. 5 W., Waynesville, Ohio, 7.5-minute quadrangle, Wayne Township, Warren County, Ohio; in American Aggregates quarry.

Core 2981. Reily, Ohio, 7.5-minute quadrangle, Reily Township, Butler County, Ohio; Ohio Coordinates (South Zone): x = 1,346,650, y = 534,900.

Core 2982. College Corner, Ohio, 7.5-minute quadrangle, Oxford Township, Butler County, Ohio; Ohio Coordinates (South Zone): x = 1,363,700, y = 565,200.

Core 2984. Mason, Ohio, 7.5-minute quadrangle, Liberty Township, Butler County, Ohio; Ohio Coordinates (South Zone): x = 1,477,800, y = 504,275.

Core 3023. NE¼NW¼SE¼ sec. 17, T. 8 N., R. 1 E., New Paris, Ohio–Indiana, 7.5-minute quadrangle, Jackson Township, Preble County, Ohio.

REFERENCES CITED

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Address of author: Helen B. Hay, deceased, formerly Geology Department, Earlham College, Richmond, IN 47374.

18. SEQUENCE STRATIGRAPHY OF THE CINCINNATIAN SERIES (UPPER ORDOVICIAN, CINCINNATI, OHIO, REGION)

by
Steven M. Holland

INTRODUCTION

Cyclicity in the Cincinnatian Series has been recognized since the earliest studies of these rocks. Orton (1878) noted several large-scale shifts in shale content within the Cincinnatian Series; these cycles were described later in more detail by many workers (most prominently by Anstey and Fowler, 1969; Hay, 1981; and Tobin 1982). These later workers argued that the Cincinnatian Series in southwestern Ohio, southeastern Indiana, and northernmost Kentucky consists of three shoaling-upward cycles characterized by systematic changes in shale percentage, bedding style, and carbonate lithology. Subsequent work in this same region, in central Kentucky, and in the Valley and Ridge Province from Tennessee to Maryland indicates that the Cincinnatian Series is composed of five sequences, each of which is dominantly shoaling upward in Ohio and Indiana (Holland, 1990, 1993). The principal features of these sequences and their implications for lithostratigraphic work are discussed in this paper.

SEQUENCE STRATIGRAPHY. A BRIEF SUMMARY

Sequence stratigraphy divides the stratigraphic record into sequences—relatively conformable successions of genetically related strata bounded by unconformities and their correlative conformities (Mitchum, 1977). Because each unconformity separates overlying strata from underlying strata that are everywhere older, the unconformities are chronostratigraphically significant surfaces. This does not imply that the magnitude of the hiatus is the same everywhere; the ages of rocks overlying or underlying the unconformity can differ considerably. This feature of unconformities allows explicit chronostratigraphic hypotheses to be framed with sequence stratigraphy, one aspect that distinguishes sequence stratigraphy from other analyses of cyclicity. Because sequences are composed of several suites of genetically related facies (these suites are called systems tracts), explicit predictions on how facies composition of a sequence changes laterally are made, thereby avoiding debates over "ideal" cycles that have plagued the cyclothem concept.

Sequence stratigraphy is undergoing rapid changes in concepts and terminology; what follows here is only a brief outline of the most important terms and concepts used in this paper (table 18-1). For a more thorough explanation, the reader is referred to Wilgus and others (1988). Sequences are characteristically tens to hundreds of meters thick and of a few million years in duration. However, these thicknesses and durations are not part of the sequence definition.

Sequence stratigraphy is not strictly a form of lithostratigraphy, nor of chronostratigraphy, nor of allostratigraphy. However, sequence stratigraphy does contain attributes of each of these forms of stratigraphy. a sequence can be thought of as a rock unit having thickness and as a time unit having a duration. Sequence stratigraphy also can be the basis of lithostratigraphic, chronostratigraphic, or allostratigraphic subdivisions. For example, the presence of unconformities can be used to define formational boundaries (Article 23 (d) of the North American Stratigraphic Code, North American Commission on Stratigraphic Nomenclature, 1983) or to define allostratigraphic units (Article 58 (c) of the Code). If unconformities represent widespread synchronous breaks in the stratigraphic record, they are physical features that can be used to define chronostratigraphic units (Article 67 of the Code).

SEQUENCE ARCHITECTURE

The sequence boundary is a surface of subaerial erosion or exposure indicating a significant hiatus (fig. 18-1). A sequence boundary passes seaward into a correlative conformable surface bearing no significant hiatus. A sequence boundary can display channeling, erosional relief, paleokarst, or other features of subaerial exposure, but also can be a nearly planar surface lacking obvious indications of subaerial exposure or erosion. The subaqueous extension of the sequence boundary—its correlative conformity—may be recognizable only by stratal termination patterns on seismic profiles.

Lying above the sequence boundary are sediments belonging to the lowstand systems tract. The lowstand systems tract is a three-dimensional unit representing all contemporaneous depositional systems present during the lowstand. In any given outcrop, however, only a few of the lowstand depositional environments will be present. Lowstand systems tracts commonly display an overall shallowing-upward trend and are composed of individual shallowing-upward units, called parasequences. A parasequence is characterized by a flooding surface at its base, a shallowing-upward succession, and is generally 1 to 10 meters (3-33 ft) thick.

The lowstand systems tract is capped by the transgressive surface, the first significant marine-flooding surface within a sequence. A marine-flooding surface is characterized by marine deposits resting in sharp contact on nonmarine deposits or by deeper water marine deposits resting in sharp contact on shallower water marine deposits. The transgressive surface is a disconformity and commmonly is demonstrably diachronous, becoming younger landward.

In shallow cratonic settings, the sequence boundary and the transgressive surface are combined into the same stratal surface, and the lowstand systems tract is absent. Where the transgressive surface and the sequence boundary are combined into a single surface, all rocks above this surface are younger than all rocks below this surface; therefore, the combined sequence boundary/transgressive surface still can be used as a chronostratigraphic marker.

Lying above the transgressive surface is a generally thin interval of transgressive deposits belonging to the transgressive systems tract. The transgressive systems tract is a three-dimensional unit representing all contemporaneous depositional systems present during the transgression. In any given outcrop, however, only one or a few of the transgressive depositional environments will be present. Transgressive systems tracts commonly display an overall deepening-upward trend, but may be composed of several parasequences.

The transgressive systems tract is capped by the maxi-

TABLE 18-1.—*Terms of sequence stratigraphy*[1]

Condensed section	a facies consisting of thin marine beds deposited at very slow rates; commonly consists of hemipelagic or pelagic sediments
Conformity	bedding surface separating younger from older strata, along which there is no evidence of erosion or nondeposition, and containing no significant hiatus
Depositional system	a three-dimensional assemblage of lithofacies
Highstand systems tract	uppermost systems tract within a sequence; overlies maximum flooding surface and underlies sequence boundary; displays aggradational to progradational parasequence stacking
Lowstand systems tract	lowermost systems tract within a sequence; overlies sequence boundary and underlies transgressive surface; displays progradational to aggradational parasequence stacking
Marine-flooding surface	surface that separates younger from older strata, across which there is evidence of an abrupt increase in water depth; commonly accompanied by minor submarine erosion; may contain a minor hiatus
Maximum flooding surface	marine-flooding surface that marks change from retrogradational to aggradational parasequence stacking; called downlap surface by Van Wagoner and others (1988)
Parasequence	relatively conformable succession of genetically related beds bounded by marine-flooding surfaces and their correlative surfaces
Sequence	fundamental unit of sequence stratigraphy; relative conformable succession of genetically related strata bounded by unconformities (sequence boundaries) and their correlative conformities
Sequence boundary	surface separating younger from older strata, along which there is evidence of subaerial erosional truncation or subaerial exposure; may indicate a significant hiatus
Systems tract	a subdivision of a sequence, defined by types of bounding surfaces, position within sequence, and stacking patterns of parasequences. Three systems tracts are recognized: lowstand, transgressive, and highstand
Transgressive surface	first significant marine-flooding surface across the shelf within a sequence
Transgressive systems tract	middle systems tract, overlies transgressive surface and underlies maximum flooding surface; displays retrogradational parasequence stacking
Unconformity	surface separating younger from older strata, along which there is evidence of subaerial erosional truncation or subaerial exposure; contains a significant hiatus. Van Wagoner and others (1988) essentially equate the terms unconformity and sequence boundary; however, to avoid confusion with the extensive presequence literature, unconformity is used here in the traditional sense, and sequence boundaries represent one particular type of unconformity
Sequence stratigraphy	study of rock relationships within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or nondeposition, or their correlative conformities

[1]Adapted from Van Wagoner and others (1988).

mum flooding surface (also called the downlap surface in seismic stratigraphy). In outcrop, the maximum flooding surface is characterized by a sharp increase in water depth, in many cases signaled by a sharp increase in shale content. Thus, transgressions commonly involve two disconformities. a lower surface (the sequence boundary/transgressive surface) that indicates initial flooding and an upper surface (the maximum flooding surface) that indicates rapid deepening.

The maximum flooding surface is overlain by the highstand systems tract. The highstand systems tract is a three-dimensional unit representing all contemporaneous depositional systems present during the highstand phase of a sequence. As for the other systems tracts, only a few of the highstand depositional environments may be present within any given local section. Highstand systems tracts commonly display an overall shallowing-upward trend and are composed of numerous shallowing-upward subunits (parasequences). The terms lowstand and highstand refer only to specific phases of a sequence and do not refer to any specific altitude of sea level; for example, every sequence contains a highstand phase whether sea level is high above or far below present sea level.

A condensed section is an interval of rock representing slow net deposition and commonly is present in the transgressive systems tract and lower highstand systems tract. Although net deposition may be very slow, condensed sections can have a complicated history of deposition, nondeposition, and erosion. Consequently a condensed section can vary widely in appearance in outcrop. Condensed sections can contain pelagic or hemipelagic deposits, abundant phosphate or glauconite, extensive burrowing, hardgrounds, anomalously abundant microfossils, or taphonomically degraded macrofossils.

SEQUENCE GENESIS

Sequences, disconformable surfaces, and systems tracts are interpreted to have formed in response to specific changes in relative sea level (fig. 18-1). Relative sea level is the sum of eustatic sea level (or sea level measured relative to some fixed reference frame) and tectonic subsidence. Note that relative sea level and water depth are not equivalent terms; for example, relative sea level could increase while water depth actually decreased—if sedimentation rate outstripped the rate of relative sea-level rise.

During times of maximum rate of relative sea-level fall, landward areas are drained and exposed to weathering, and streams incise to form a sequence boundary. The fall of relative sea level shifts deposition basinward. The lowstand systems tract forms and continues to develop as relative sea level stops falling and begins to rise slowly. Because of the low relief of cratonic areas, lowstand deposition may be confined to shelf margins and slopes, leaving the craton exposed. As the rate of sea-level rise increases, landward areas are flooded, and a transgressive surface forms, initiat-

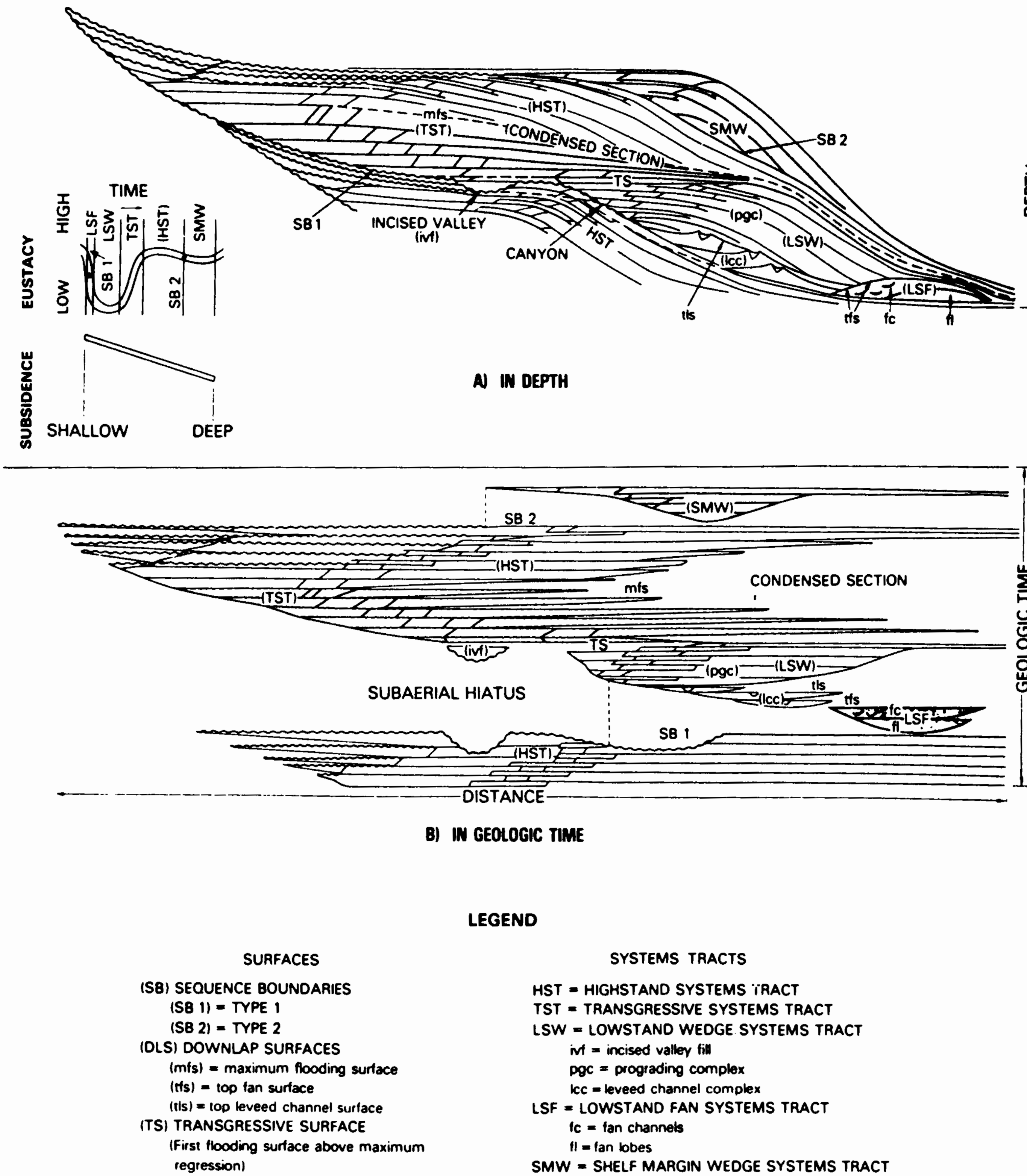

FIGURE 18-1.—Cross sections of a stratigraphic sequence, plotted in thickness (upper drawing) and geologic time (lower drawing). See table 18-1 for definitions of terms. From Haq and others (1987).

ing the transgressive systems tract. Rising sea level traps terrigenous sediment in estuaries and lagoons as on the Atlantic Coast today. In addition, the rate of sea-level rise commonly exceeds the deposition rate for all nonreefal carbonates, particularly where water is deeper than a few meters. Thus, in both siliciclastic and carbonate settings, rapid sea-level rise concentrates deposition in shallow nearshore and estuarine areas, but starves all other areas of sediment. A condensed section characteristically begins to form during this time and into early highstand time. Transgressive systems tracts generally deepen upward and typically are thin because depositional rates are generally slow during a transgression. A maximum flooding surface forms and signals the beginning of highstand deposition, when the rate of sea-level rise reaches a maximum. As sea-level rise slows and eventually begins to fall, sediments are no longer hindered from dispersal to the shelf, and the areas in which condensed sections were forming retreat. Because highstand sedimentation rates are higher and because relative sea level is either slowly rising or falling, highstand systems tracts generally shallow upward.

FACIES AND DEPOSITIONAL ENVIRONMENTS

Although at first glance the Cincinnatian Series may seem a monotonous pile of limestones and shales, it contains a number of discrete facies that can be defined on purely lithologic criteria, if one wishes to equate facies with formal lithostratigraphic nomenclature (discussed on p. 146). The lithologic definition of a facies can be supplemented with paleontologic criteria such as characteristic fossil assemblages, ichnology, and taphonomy to aid in field identification, particularly where an outcrop is small or poor. Of the numerous facies descriptions of the Cincinnatian Series (for example, Hay, 1981; Tobin, 1982; Weir and others, 1984; Holland, 1990), most of the facies recognized in the various studies are largely synonymous (table 18-2). The descriptions of the principal Cincinnatian facies are listed in tables 18-3 and 18-4. More detailed descriptions can be found in the references listed above.

HIGHSTAND SYSTEMS TRACT FACIES

The highstand facies consistently are stacked into conformable, shallowing-upward hemicycles, such that a deeper water facies grades upward into a shallower water facies. Where a deeper water facies overlies a shallower water facies, the contact is invariably sharp, and the two highstand facies commonly are separated by a very thin transgressive facies. The consistent stacking of highstand facies into a repeated vertical shallowing-upward succession suggests highstand deposition along a series of shore-parallel belts on a gently sloping, mixed-carbonate-clastic ramp. The northward pinchout of supratidal and intertidal facies and the southward pinchout of deeper subtidal facies indicate a northward-dipping ramp. Megaripples, groove casts, gutter casts, and aligned fossils also indicate northward-directed storm flow downramp (Hofmann, 1966; Meyer and others, 1981; Jennette, 1986; Duke, 1990).

Highstand facies form the bulk of the Cincinnatian Series, and the subtidal highstand facies that dominate the Cincinnatian Series in its type area are quite similar to one another at first glance. Closer examination reveals numerous and in some cases subtle differences between facies. Several depth trends are apparent within the highstand facies (table 18-3). The deepest subtidal facies exposed at the surface (the shale-dominated facies) contains abundant shale and dominantly fine grained carbonate lithologies. Fossil morphologies tend to be thin and fragile (for example, the brachiopods *Resserella* and *Sowerbyella*), and multi-element skeletons of arthropods and echinoderms commonly are articulated. (Note: some workers prefer the name *Onniella* instead of the name *Resserella* for the forms found in the type-Cincinnatian.) Shell breakage, abrasion, encrustation, and boring are generally low. Bioturbation is limited to discrete traces of the *Cruziana* ichnofacies. Deep-water storm beds are dominated by distal types, characterized by relatively thin, basal shell lags; thick, laminated to hummocky, cross-stratified siltstones; and thick capping shales (Aigner, 1985). Collectively, these features suggest offshore deposition in generally quiet water disturbed only by major storms.

The mixed packstone-shale facies is intermediate between the shale-dominated facies and the wavy/nodular limestone facies in nearly all aspects, including shale content, carbonate grain size, fossil morphologies, taphonomy, ichnofacies assemblage, and storm-bed structure. Peak species diversity and morphological variability are reached in this facies. Given its intermediate character and stratigraphic position, the mixed packstone-shale facies was deposited within the transition zone, where the water was agitated frequently by storms.

The shallowest subtidal facies (wavy/nodular limestone) is characterized by less shale. Carbonate lithologies are commonly coarse grained. Fossil morphologies are characteristically thick and robust (for example, the articulate brachiopods *Platystrophia* and *Hebertella*, and thick ramose to massive trepostome bryozoans), and multi-element skeletons are more rarely articulated than in deeper water facies. Shell breakage, abrasion, encrustation, and boring are variable, but commonly are more intense than in deeper water facies. Bioturbation is pervasive, and the few discrete traces are elements of the *Skolithos* ichnofacies. Shallow-water storm beds are dominated by proximal types characterized by an upward succession of thick basal shell lags, thin or absent laminated siltstones, and thin fossiliferous capping shales (Aigner, 1985). These features, taken together with the stratigraphic position of this facies, suggest deposition in the shoreface zone. However, the presence of an abundant, sessile, soft-bottom epifauna and thoroughly bioturbated sediments indicates that this environment was not subject to large breaking waves, but instead was a fairly low energy shoreface.

The intertidal and supratidal portions of the shallowing-upward highstand deposits are not well exposed in most of Ohio and Indiana. Intertidal facies of the Cincinnatian Series are characterized by a pervasively bioturbated fabric and generally lack abundant and diverse body fossils; ramose trepostome bryozoans are the most abundant form. The supratidal facies contains abundant desiccation cracks and parallel lamination and uncommon vertical burrows, but lacks bioturbated texture and body fossils.

TRANSGRESSIVE SYSTEMS TRACT FACIES

Transgressive facies in the Cincinnatian Series are unusual in several respects. They are generally thin, always less than 5 meters (16.4 ft) thick, and generally less than 2 meters (6.6 ft) thick. They are geographically restricted, commonly traceable for only tens of kilometers rather than hundreds. Although highstand facies are generally similar to one another, transgressive facies are unlike each other or any highstand facies in their combination of grain size, sedimentary structures, bedding, faunal composition, and taphonomy. Although contact relationships between successive highstand facies are highly predictable, contact relationships between transgressive facies and overlying and underlying highstand facies are less predictable. Transgres-

TABLE 18-2.—*Synonymy of Cincinnatian Series facies and lithostratigraphic nomenclature*

Facies of this paper and Holland (1990)	Facies of Tobin (1982), Tobin (1986)	Facies of Hay (1981), Hay and others (1981)	Facies of Weir and others (1984)	Previous lithostratigraphic nomenclature
Laminated Carbonate Mudstone (LCM)	Facies D	did not name	M. Dolomite and calcitic dolomite	Parts of Saluda, Preachersville, Rowland, Terrill, and Tate
Bioturbated Carbonate Mudstone (BCM)	Faciés D	did not name	K. Dolomitic mudstone L. Dolomitic mudstone and dolomite	Parts of Saluda, Preachersville, Rowland, Terrill, and Tate
Variegated Mudstone (IVM)	Facies D	tentatively assigned to 1a	not studied	Parts of Preachersville and Elkhorn
Wavy/Nodular Limestone (WNL)	Facies C	3a, 3b, 3c, 3d	E. Nodular-bedded fossiliferous limestone and shale F. Nodular-bedded limestone and calcarenite G. Nodular-bedded mudstone	All of Whitewater, Oregonia, Reba, Mt. Auburn, Straight Creek, Stingy Creek, and Bellevue; parts of Calloway Creek, Grant Lake, and Bardstown
Mixed Packstone-Shale (PS)	Facies B	2a, 2b	A. Thin-bedded fossiliferous limestone B. Even-bedded fossiliferous limestone and shale C. Even-bedded fossiliferous limestone and shale	All of Liberty, "Sunset" (of Tobin, 1986, not Weir and others, 1984), Corryville, Fairview, and Clays Ferry; parts of Calloway Creek, Grant Lake, and Bardstown
Shale-Dominated (SD)	Facies A	1a, 1b	D. Shale and fossiliferous limestone	All of Waynesville and Kope
Wavy-Bedded Wackestone (WBW)	Facies D	4d	I. Micrograined limestone N. Dolomitic limestone and mudstone	All of Hitz Bed, Sunset (of Weir and others, 1984, not Tobin 1986), and Gilbert; parts of Saluda and Marble Hill Bed
Cross-Bedded Calcarenite (CBC)	not encountered in study	4a, 4b	F. Nodular-bedded limestone and calcarenite (in part) H. Calcarenite	Never separately named, generally incorporated in WNL units
Bioclastic Packstone (BP)	not distinguished as separate facies	3a	not distinguished as separate facies	Never separately named, generally incorporated in WNL units
Gastropod Coquina (GC)	not encountered in study	4c	not separately named as facies	Parts of Marble Hill Bed

sive facies always lie between overlying highstand facies that formed in shallower water than underlying highstand facies; in other words, they always occur in a transgressive position.

Because of the thinness of the transgressive systems tract, geographic relationships of the transgressive facies are much better known than the stacking relationships. The transgressive systems tract is always thin, but is thicker in landward areas characterized by the wavy-bedded wackestone facies (table 18-3). The wavy-bedded wackestone facies (WBW) is characterized by bioturbated wackestones with pinch-and-swell bedding. Faunally, WBW is dominated by a stromatoporoid-tabulate coral-molluscan assemblage, but lacks abundant typical open-marine fauna such as brachio-

TABLE 18-3.—*Highstand facies*

Lithofacies	Lithologies	Bedding[1]	Sedimentary structures	Body-fossil assemblage	Taphonomy	Trace fossils
Supratidal Laminated Carbonate Mudstone (LCM)	calcareous to dolomitic mudstone	planar lamination, even and regular	ubiquitous planar lamination, wave-ripple lamination, abundant desiccation cracks	absent	—	short *Skolithos*?
Intertidal Bioturbated Carbonate Mudstone (BCM)	calcareous to dolomitic mudstone	very thin to medium bedded, unevenly but regularly bedded	rare desiccation cracks, wave-ripple lamination	scarce; thick ramose bryozoans, locally a rugosan-stromatoporoid assemblage	calcitic forms preserved or locally dolomitized; moderate to severe breakage	discrete burrows to pervasive bioturbation; *Chondrites*, *Palaeophycus*
Intertidal Variegated Mudstone (IVM)	mudstone (95%), siltstone or dolomitized wackestone/ packstone (5%)	indistinct in mudstones; thin to very thin siltstones, wackestones, and packstones	ripple-lamination	elements of the *Hebertella* assemblage: *Hebertella*, ramose trepostome bryozoans, cyclostome bryozoans	recrystallized and dolomitized calcitic forms; moderate breakage	pervasive bioturbation; *Palaeophycus* in siltstones
Shoreface Wavy/ Nodular Limestone (WNL)	fossiliferous packstone (70%), fossiliferous mudstone (30%); minor wackestone, grainstone, and calcisiltite	very thin bedded, evenly but irregularly bedded	proximal storm beds, wave-ripple lamination, gutter casts	*Hebertella* assemblage: large thick-shelled brachiopods (*Hebertella*, *Platystrophia*, *Rafinesquina*); common thick ramose and massive bryozoans; also pelecypods, gastropods, cephalopods, crinoids, and trilobites	calcitic shells well preserved in both limestones and shales; aragonitic forms preserved as molds; breakage and abrasion variable, but generally moderate to severe; widespread boring and encrustation	pervasive bioturbation; *Skolithos* assemblage: *Skolithos*, uncommon cone-shaped hypichnia
Transition Zone Mixed Packstone-Shale (PS)	fossiliferous packstone (45%), mudstone (45%), wackestone, grainstone, and calcisiltite (10% total)	medium to very thin, evenly bedded, meter-scale cycles	storm beds, planar laminations, wave-ripple lamination, small-scale hummocky cross-lamination	mixed brachiopod-bryozoan assemblage: wide range of brachiopod and bryozoan taxa and morphologies; also pelecypods, gastropods, trilobites, and echinoderms	calcitic shells preserved, aragonitic forms preserved as molds; negligible to moderate breakage and abrasion (rarely severe); common articulated multi-element skeletons	mixed *Cruziana*-*Skolithos* ichnofacies: *Chondrites*, *Diplocraterion*, *Trichophycus*, *Palaeophycus*
Offshore Shale-Dominated (SD)	mudstone (70%), fossiliferous wackestone and packstone (20%), crinoidal grainstone (5%), calcisiltite (5%)	thin to thick, uneven to cyclical meter-scale cycles	storm beds, small-scale hummocky and trough cross-lamination, megaripples, gutter casts, groove casts, runzelmarken	*Onniella* assemblage: small, thin, flat brachiopods (*Onniella*, *Sowerbyella*, small *Rafinesquina*); also ramose bryozoans, trilobites (including blind forms such as *Cryptolithus*), crinoids, graptolites	calcitic shells preserved, aragonitic forms preserved as molds; variable shell breakage and low shell abrasion; common to abundant articulated multi-element skeletons	*Cruziana* ichnofacies: *Chondrites*, *Diplocraterion*, *Trichophycus*, *Rusophycus*, *Diplichnites*

[1]Bedding terminology of Ingram (1954).

TABLE 18-4.—*Transgressive facies*

Lithofacies	Lithologies	Bedding[1]	Sedimentary structures	Body-fossil assemblage	Taphonomy	Trace fossils
Wavy-Bedded Wackestone (WBW)	wackestone to micstone (80%), mudstone (20%)	medium wavy-bedded carbonates, regular but uneven; very thin mudstone beds	normal grading; planar lamination	stromatoporoid-tabulate coral-molluscan assemblage, including ramose bryozoans and ostracodes; grades upward into *Hebertella* assemblage	both calcitic and aragonitic bioclasts preserved intact or recrystallized; breakage and abrasion low	*Skolithos* assemblage to burrow-mottled *Skolithos*
Cross-Bedded Calcarenite (CBC)	calcarenite (90%), fossiliferous mudstone (10%)	medium- to thick-bedded carbonates, irregular to broadly lenticular beds, sigmoidal shaped; very thin mudstone beds	low-angle tabular cross-bedding, trough cross-bedding, erosional base to facies	thick-shelled elements of *Hebertella* assemblage	comminuted bioclasts; highly abraded, broken and bored bioclasts; some brachiopod shells phosphatized	absent
Bioclastic Packstone (BP)	bioclastic wackestone and packstone (80%), fossiliferous mudstone (20%)	medium bedded, irregular and uneven, lenticular in places	megaripples, cross-lamination, amalgamation	variable; generally contains deepening-upward sequence from *Hebertella* assemblage to mixed brachiopod-bryozoan assemblage to *Onniella* assemblage	highly abraded, broken and bored, but not as intensely as in cross-bedded calcarenite facies; phosphatic steinkerns of gastropods, pelecypods, and bryozoans	absent
Gastropod Coquina (GC)	gastropod grainstone (50%), crinoidal calcarenite (50%)	medium to thick bedded, tabular, even, regular	cross-lamination	almost entirely the gastropod *Loxoplocus* and crinoid ossicles; fragments of bryozoans and *Hebertella*	gastropods largely unbroken and unabraded, shell material dolomitized and lined internally and externally with calcite; other elements highly abraded and broken	*Skolithos* locally

[1]Bedding terminology of Ingram (1954).

pods, echinoderms, and trilobites. These features and the paleogeographic setting of WBW in the most upramp areas are consistent with quiet shallow-water deposition, such as lagoons.

Wavy-bedded wackestones are bounded downramp by the cross-bedded calcarenite facies (CBC). This facies contains abundant sand-wave-scale cross-bedding and is dominated by echinodermal grains, highly abraded brachiopods, and massive bryozoans. CBC is limited to narrow (approximately 10 km/6 miles) shore-parallel belts, suggesting deposition as a series of bars or shoals, which may have protected the lagoons from wave energy.

The cross-bedded calcarenite facies is bounded downramp by very widespread but thin deposits of bioclastic packstones (BP). This facies is characterized by a consistently taphonomically degraded fauna that is intensely broken and abraded. BP is commonly enriched in resistant echinodermal grains and in phosphatic steinkerns of molluscan protoconchs and bryozoan zooecia. The bioclastic packstone lithology is not unusual in the Cincinnatian Series and is present in nearly all facies, but the bioclastic packstone facies is distinctive in that it commonly occurs just above the sequence boundary in downramp sections and appears in outcrop as an anomalous band of tabular limestones.

The gastropod coquina is an unusual facies in the Cincinnatian Series; it occurs at the base of the C4 sequence (see below) over a few square kilometers near Bedford, Kentucky. It consists of a series of decimeter-scale fining-upward units that grade from gastropod coquina into crinoidal grainstones. Faunally, it is dominated by abundant, nearly unbroken high-spired gastropods of the genus *Loxoplocus* and by echinodermal grains. Brachiopods and bryozoans occur sparingly and are highly abraded. On the basis of its geometry as a single, narrow, shore-parallel body and three shore-perpendicular tongues, the gastropod coquina is interpreted as a bar and tidal-channel system (Swadley, 1979).

Florida Bay is a possible modern analog to the Cincinnatian Series transgressive systems tract. Florida Bay is an expanse of subtidal to supratidal seagrass beds that currently are forming mottled wackestones (Parkinson and Meeder, 1989). These seagrass beds are bounded seaward by a series of islands composed of coarse shell debris; these islands are bounded seaward by extensive poorly sorted shelly sand bottoms (Aigner, 1985).

Of the transgressive facies, only the bioclastic packstone facies is widely distributed in Ohio and Indiana. The wavy-bedded wackestone facies, cross-bedded calcarenite facies, and gastropod coquina facies are best developed in upramp areas of central Kentucky.

DESCRIPTIONS OF CINCINNATIAN SEQUENCES

The character of the Cincinnatian sequences changes laterally, especially into upramp areas of central Kentucky (fig. 18-2). However, in southeastern Indiana, southwestern Ohio, and northernmost Kentucky, the character of each of the Cincinnatian sequences is remarkably constant (figs. 18-3 and 18-4). The Cincinnatian sequences are numbered sequentially from oldest (C1) to youngest (C5). Mohawkian sequences are currently under study and will be similarly numbered, with an M prefix; preliminary results suggest the presence of three Mohawkian sequences in the Cincinnati Arch, Nashville Dome, Valley and Ridge, and Upper Mississippi Valley areas.

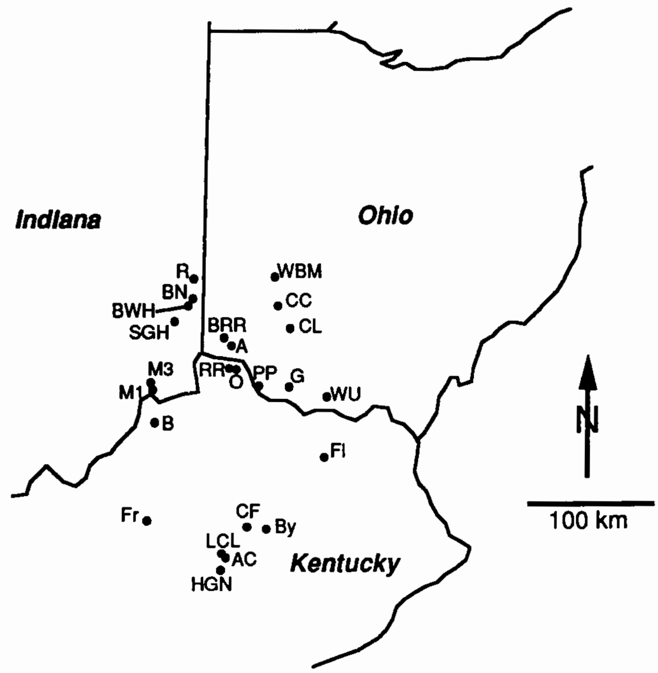

FIGURE 18-2.—Map showing locations of sections in figures 18-3 and 18-4. A, Aiken High School (OH-HA-0012); AC, Ashlock Cemetery; B, Bedford; BN, Brookville North (= Garr Hill, IN-FR-0003); BRR, Blue Rock Road (OH-HA-0005); BWH, Bon Well Hill (IN-FR-0001); By, Bybee; CC, Caesar Creek spillway and dam (OH-WA-0001, OH-WA-0002); CF, Clays Ferry; CL, Cowan Lake (OH-CN-0001); Fl, Flemingsburg; Fr, Frederickstown; G, Georgetown (OH-BR-0006); HGN, Halls Gap North; LCL, Lincoln County Line; M1, Madison #1 (IN-JE-0003); M3, Madison #3 (IN-JE-0001); O, Orphanage Road (KY-KE-0003); PP, Point Pleasant (OH-CT-0020); R, Richmond (= Richmond-U.S. Route 27, IN-WY-0001); RR, Riedlin Road (KY-KE-0001); SGH, South Gate Hill (IN-FR-0005); WU, West Union (OH-AD-0004); WBM, Wright Brothers Memorial. See section on Localities (p. 149-150) for descriptions.

C1 SEQUENCE

The C1 sequence is the longest and thickest of the Cincinnatian sequences. Spanning all of the Edenian Stage and most of the Maysvillian Stage, it represents some 6 million years. The C1 sequence is approximately 105 meters (344 ft) thick at Cincinnati and thins southward into central Kentucky.

In the type-Cincinnatian area, the C1 sequence is composed in vertical sequence of the Kope, Fairview, and Bellevue Formations. The C1 sequence boundary is placed at the contact between the Kope Formation and the Point Pleasant Formation and is well exposed in stream cuts near Point Pleasant, Ohio (OH-CT-0020), and in road cuts along U.S. Route 52 near the Beckjord Coal Plant (OH-CT-0019). Here, the shale-dominated facies belonging to the Kope Formation overlies mixed packstone-shale facies of the Point Pleasant Formation. A 1-meter-thick (3.3-ft-thick) interval dominated by cross-bedded and megarippled packstones at the top of the Point Pleasant may constitute the bioclastic packstone facies of the transgressive systems tract. The water depths near the base of the Kope Formation are probably the greatest achieved in the type-Cincinnatian, as the fauna is characterized by abundant graptolites and the deep-water trilobite *Triarthrus*. The Kope Formation grades upward into the mixed packstone-shale facies of the Fairview

Formation, which in turn grades upward into the wavy/nodular limestone facies of the Bellevue Formation. This shoaling-upward succession is well exposed in long road cuts along Interstates 275 and 471 in northern Kentucky. Overall, the C1 sequence at Cincinnati is dominated by the shoaling-upward succession from offshore to shoreface environments.

In central Kentucky, the C1 sequence boundary is placed at the sharp contact between the mixed packstone-shale facies of the Clays Ferry Formation and the cross-bedded calcarenites and wavy/nodular limestones of the Lexington Limestone. The C1 sequence boundary is well exposed along Kentucky Route 2328 at Clays Ferry, Kentucky. As at Cincinnati, a thin interval of megarippled and taphonomically degraded packstones at the contact may represent the bioclastic packstone facies of the transgressive systems tract. Alternatively, the transgressive systems tract may be absent here, in which case the sequence boundary, transgressive surface, and maximum flooding surface are combined into a single stratal surface. The top of the Clays Ferry Formation is marked by the Garrard Siltstone, a thick interval of convolute-bedded siltstones. The Garrard Siltstone may correlate lithostratigraphically and chronostratigraphically to thinner convolute-bedded siltstones with well-developed ball-and-pillow structures exposed from Maysville, Kentucky, to Batavia, Ohio (for example, Maysville/KY-MS-0002 and Chicken Hollow Road/OH-BR-0001 localities). These thinner siltstone units lie within the Fairview Formation and occur in approximately the same stratigraphic position as the Garrard Siltstone. Above the Garrard Siltstone is the mixed packstone-shale facies of the lower Calloway Creek Formation, which grades upward into the wavy/nodular limestones of the upper Calloway Creek Formation, which grade upward into the bioturbated and laminated calcareous mudstones of the Tate Formation. The C1 sequence in central Kentucky is dominated by a shallowing-upward succession from transition zone to supratidal environments, a shallower suite of environments than at Cincinnati.

C2 SEQUENCE

Spanning the upper part of the Maysvillian Stage, the C2 sequence represents only 1 million years. At Cincinnati, the C2 sequence is approximately 12 meters (39 ft) thick. The C2 sequence thins to the south; in central Kentucky, it is approximately 10 meters (33 ft) thick.

In the type-Cincinnatian area, the C2 sequence boundary is placed at the contact between the mixed packstone-shale facies of the Corryville Formation and the wavy/nodular limestone facies of the Bellevue Formation. The character of the sequence boundary changes across the Cincinnati area. At Madison, Indiana (IN-JE-0001, IN-JE-0002, and IN-JE-0003), the sequence boundary is poorly exposed, but seems to lack any transgressive deposits such as bioclastic packstones. At Muddy Creek in Cincinnati (OH-HA-0020), the sequence boundary is marked by a single thick bed of bioclastic packstone at the sharp facies contact between the Corryville and Bellevue. Near Georgetown, Ohio (OH-BR-0006), the sequence boundary is not as sharp, but is placed at the sharp change from nodular bedding to tabular bedding. Several hardgrounds are present at this bedding change. The Corryville Formation grades upward into the wavy/nodular limestones of the Mt. Auburn Formation. The overall succession of the C2 sequence at Cincinnati passes from transition zone to shoreface environments.

In central Kentucky, the C2 sequence boundary is placed at the sharp contact between the wavy-bedded wackestones of the Gilbert Formation and the laminated carbonate mudstones of the Tate Formation. The sequence boundary here is unremarkable except for its sharpness; it is not burrowed, enriched in glauconite or phosphate, nor does the surface bear more than a few centimeters of relief or obvious evidence of karstification. The wavy-bedded wackestones grade rapidly over a few tens of centimeters into wavy/nodular limestones of the Stingy Creek Formation; this zone of rapid gradation is equivalent to the maximum flooding surface. The Stingy Creek Formation grades upward into the bioturbated and laminated carbonate mudstones of the Terrill Formation. The overall succession of the C2 sequence in central Kentucky passes from lagoonal transgressive deposits upward into shoreface and supratidal environments. The C2 sequence in central Kentucky contains a thicker transgressive systems tract than at Cincinnati and a shallower suite of highstand facies.

C3 SEQUENCE

The C3 sequence represents slightly more than 1 million years and is limited to the basal Richmondian Stage. The C3 sequence is approximately 20 meters (66 ft) thick at Cincinnati and thins southward to 15 meters (49 ft) in central Kentucky.

In the type-Cincinnatian area, the C3 sequence boundary is placed at the contact between the mixed packstone-shale facies of the "Sunset Formation" and the wavy/nodular limestone of the Mt. Auburn Formation (see section on Comments on Cincinnatian lithostratigraphic nomenclature for discussion of Sunset usage). The C3 sequence boundary is well exposed at Blue Rock Road (OH-HA-0005) and is marked by a single thick bed of medium-grained bioclastic packstone at the sharp facies contact. The C3 sequence boundary is poorly exposed at Madison, Indiana (IN-JE-0001, IN-JE-0002, and IN-JE-0003), where transgressive deposits appear to be absent. The mixed-packstone shale facies grades upward into the wavy/nodular limestone facies of the Oregonia Formation. Note that the C3 sequence in the type-Cincinnatian corresponds to the entire Arnheim Formation, originally composed of the Sunset and Oregonia Members. The C3 sequence in the type-Cincinnatian is dominated by a shoaling-upward succession from transition zone to shoreface environments.

In central Kentucky, the C3 sequence boundary is marked by the sharp contact between the wavy-bedded wackestones of the Sunset Formation and the laminated carbonate mudstones of the Terrill Formation. The sequence boundary is well exposed at the Lincoln County Line locality, where it is sharp but otherwise unremarkable. The C3 sequence boundary also is well exposed at Frederickstown. Somewhat to the north at Bedford and Flemingsburg, the C3 sequence boundary is placed at the base of cross-bedded calcarenites, which are sharply overlain by wavy/nodular limestones of the Reba Formation. The wavy-bedded wackestones grade over several tens of centimeters into the wavy/nodular limestones of the Reba Formation, which grade upward into the bioturbated and laminated carbonate mudstones of the Rowland Formation. The C3 sequence in Kentucky is very similar in architecture to the C2 sequence in Kentucky; it consists of transgressive lagoonal deposits overlain by a shallowing-upward highstand succession passing from shoreface into supratidal environments. C3 transgressive deposits are thicker in central Kentucky than near Cincin-

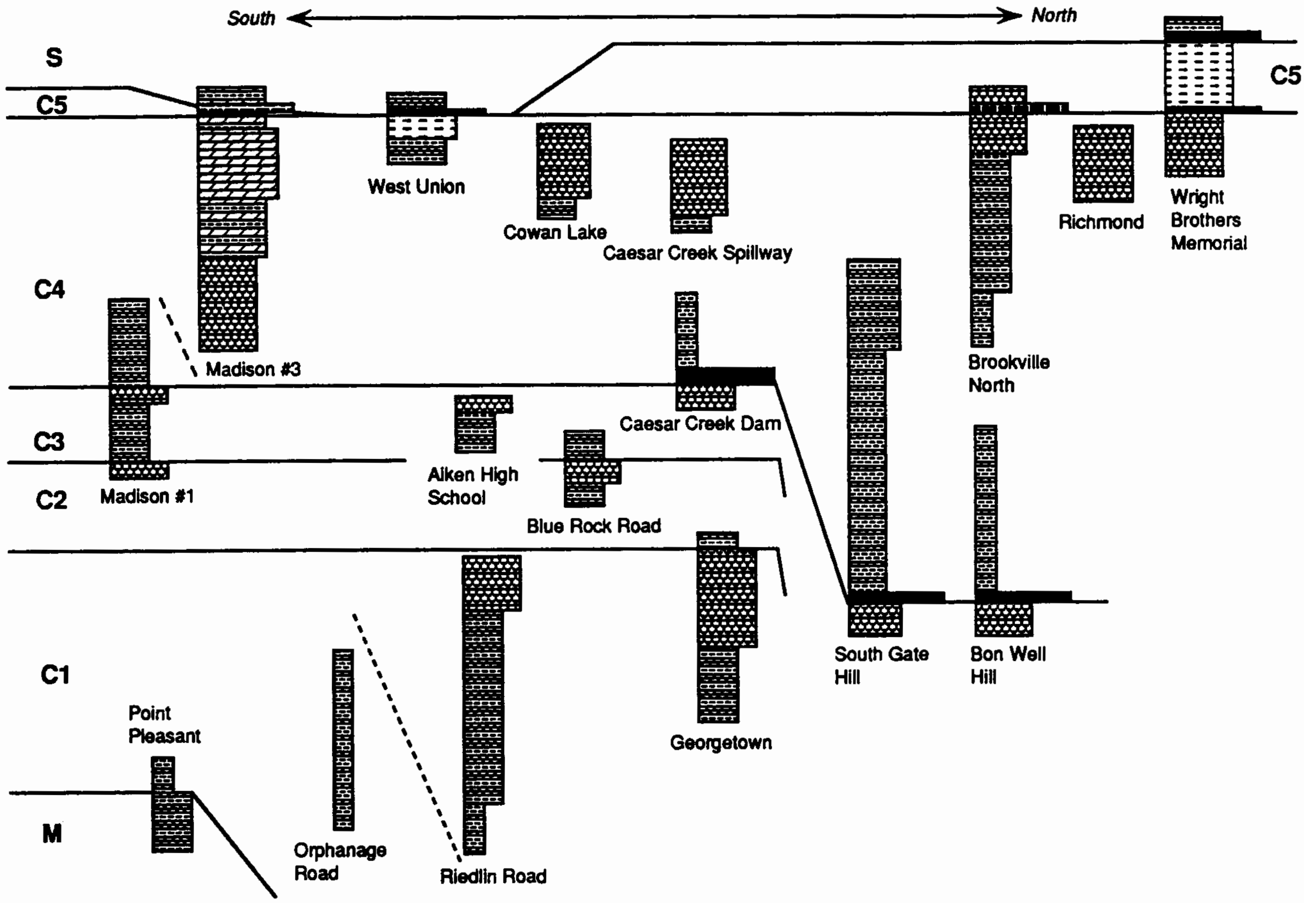

FIGURE 18-3.—Measured sections of the northern Cincinnati Arch. See figure 18-2 for locations and figure 18-4 for explanation of facies patterns. Sections generally are arrayed from south to north, from left to right. Sequence boundaries are indicated by horizontal lines connecting sections. Because of the thinness of the transgressive units, correlations of the maximum flooding surface are not drawn; at this scale, they commonly would be plotted on the same line as the sequence boundaries. Where the transgressive units are thick (for example, Caesar Creek dam and South Gate Hill), the maximum flooding surface lies at the upper surface of the transgressive facies. Letters C1-C5 along left side indicate sequence number; M = an unnumbered Mohawkian sequence, and S = Silurian rocks.

nati, and a shallower suite of highstand environments is developed in Kentucky.

C4 SEQUENCE

The C4 sequence represents just over 2 million years and spans the majority of the Richmondian Stage. The C4 sequence is approximately 60 meters (197 ft) thick near the type area of the Richmondian Stage at Richmond, Indiana, and thins southward to central Kentucky, where it is 11 meters (36 ft) thick.

In the type-Cincinnatian area, the C4 sequence boundary is placed at the base of the 1.5-meter (5-ft) interval of bioclastic packstones that are traditionally regarded as the uppermost part of the Oregonia Formation. These bioclastic packstones are well exposed at Bon Well Hill (IN-FR-0001) and Caesar Creek spillway (OH-WA-0001) and dam (OH-WA-0002) and consist of taphonomically degraded brachiopods and bryozoans in a disarticulated-echinoderm-rich packstone. The packstone beds are rich in phosphatic steinkerns of mollusks and bryozoan zooecia, are cross bedded, and display an overall faunal deepening-upward sequence passing from a shallower, *Rafinesquina*-dominated assemblage into a deeper water, *Resserella*-dominated assemblage. (Note: some workers prefer the name *Onniella* instead of the name *Resserella* for the forms found in the type-Cincinnatian). The upper surface of this packstone interval is a sharp contact with the overlying shale-dominated facies of the Waynesville Formation; this contact represents the maximum flooding surface. The shale-dominated facies of the Waynesville grades upward into the mixed packstone-shale facies of the Liberty Formation, which grades upward into the wavy/nodular limestone facies of the Whitewater Formation. On the western side of the Cincinnati Arch, the Whitewater (known in older usage as the Lower Whitewater) grades upward into the bioturbated and laminated carbonate mudstone facies of the Saluda Formation. The bioturbated carbonate mudstones contain prominent heads of the tabulate coral *Tetradium*. On the eastern side of the Cincinnati Arch, the C4 interval is poorly exposed and many of the lithofacies are somewhat shalier, but show the same shoaling-upward faunal succession passing from an offshore *Resserella*-dominated assemblage to a transition-zone mixed brachiopod-bryozoan assemblage to a shoreface *Hebertella*-dominated assemblage. Although its assignment to the C4 sequence is tentative, the intertidal variegated mudstone facies is present on the east side of the Cincinnati Arch at West Union (OH-AD-0004). Despite the differences between facies on the east and west sides of the Cincinnati Arch, the overall C4 succession passes from a thin zone of transgres-

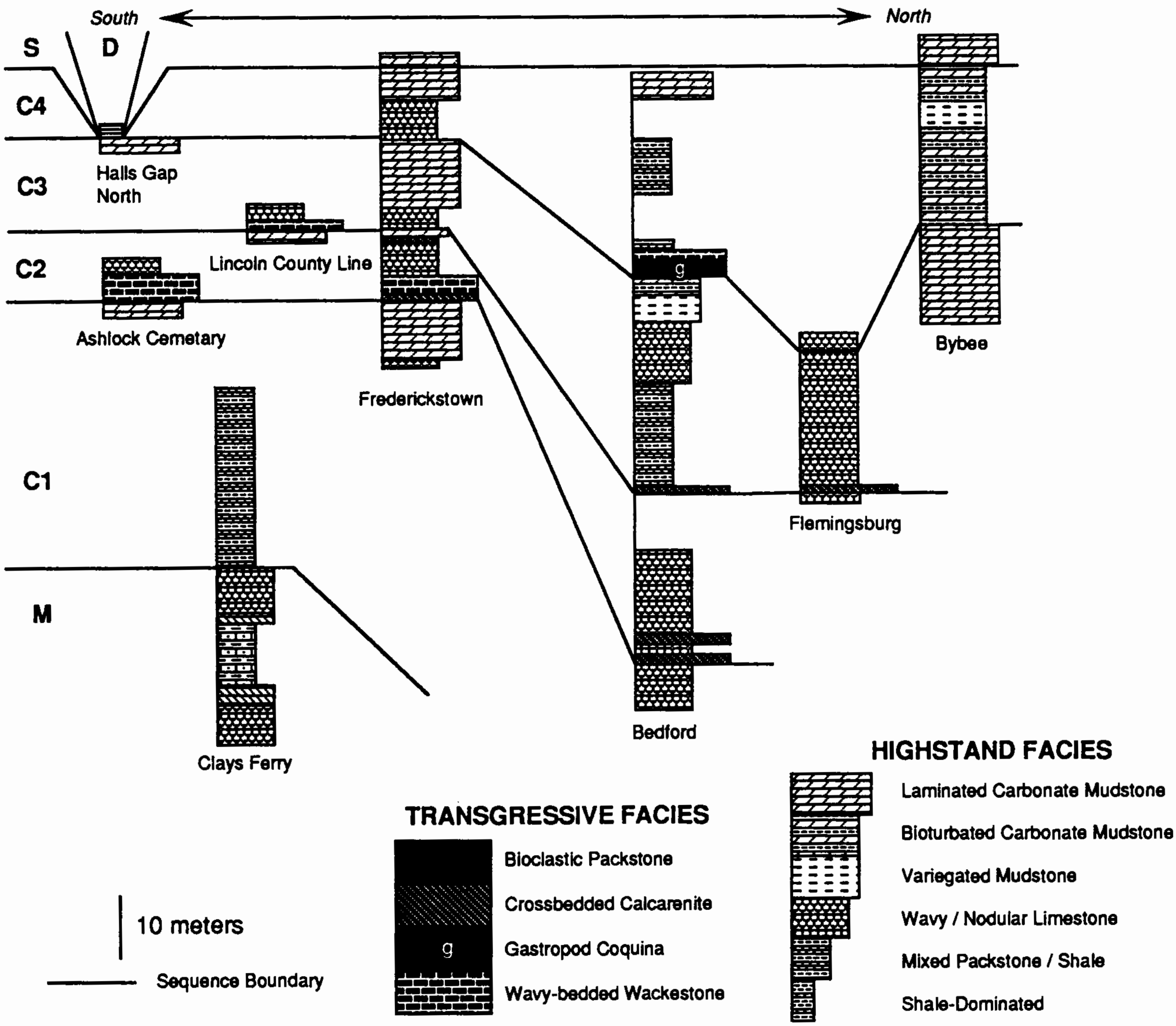

FIGURE 18-4.—Measured sections of the southern Cincinnati Arch. See figure 18-3 for explanation. D above Halls Gap North section indicates Devonian rocks (New Albany Shale).

sive bioclastic packstones into highstand facies that shallow upward from offshore to intertidal environments.

In central Kentucky, the C4 sequence and its sequence boundary are variable, suggesting somewhat greater paleotopography. At Bybee, the sequence boundary is placed at the sharp contact between bioturbated carbonate mudstones of the Preachersville Formation and laminated carbonate mudstones of the Rowland Formation. The sequence passes upward into the variegated mudstone facies and back into the bioturbated carbonate mudstone facies, both of the Preachersville Formation, but otherwise shows little environmental change. At Frederickstown, the sequence boundary is more obvious and is placed at the sharp contact between laminated carbonate mudstones of the Rowland Formation and 1 meter (3.3 ft) of bioclastic packstones of the Bardstown Member of the Drakes Formation. These bioclastic packstones are sharply overlain by wavy/nodular limestones of the Bardstown Member; this contact represents the maximum flooding surface. The wavy/nodular limestones grade upward into bioturbated and laminated carbonate mudstones of the Saluda Formation. At Bedford, the C4 sequence boundary is marked by the base of the only deposit of gastropod coquina in the Cincinnatian; this gastropod coquina is named the Marble Hill Bed, and it sharply overlies bioturbated carbonate mudstones of the Rowland Formation. The gastropod coquina is sharply overlain by wavy-bedded wackestones, which are sharply overlain by mixed packstone-shale facies of the Liberty Formation; the sharp contact at the base of the Liberty is the maximum flooding surface. The Liberty grades upward into wavy/nodular limestones of the Whitewater Formation, which grades upward into bioturbated and laminated carbonate mudstones of the Saluda Formation. At Flemingsburg, the C4 sequence boundary is obscure and poorly exposed; it is placed at a horizon marking an increase in shale and the first occurrence of a number of distinctive C4 taxa, including the rugose coral *Grewingkia* and *Streptelasma* and the articulate brachiopods *Thaerodonta*, *Glyptorthis*, and *Hiscobeccus*. (Note. some workers assign *Hiscobeccus* to the genus *Lepidocyclus*.) Overall, the C4 sequence in central Kentucky shows only localized transgressive deposits and variable amounts of shoaling during the highstand, but, in general, a shallower suite of facies than at Cincinnati.

C5 SEQUENCE

The C5 sequence is the thinnest and briefest of the Cincinnatian sequences. Limited to the uppermost Richmondian, it represents fewer than a half a million years, although some strata may have been removed by latest Ordovician and earliest Silurian erosion. The C5 sequence is 11 meters (36 ft) at its thickest measured section at the Wright Brothers Memorial and pinches out to the south in northern Kentucky.

The C5 sequence boundary is placed at the base of wavy-bedded wackestones of the "Saluda Formation" and the Hitz Bed, where they overlie bioturbated and laminated carbonate mudstones of the true Saluda Formation. The C5 sequence boundary is well exposed at Madison (IN-JE-0001, IN-JE-0002, and IN-JE-0003) and at Garr Hill (= Brookville North, IN-FR-0003). The wavy-bedded wackestones are sharply overlain by wavy/nodular limestones of the Upper Whitewater Formation (as known in older literature); this contact is the maximum flooding surface. In northernmost outcrop areas, the wavy/nodular limestones grade upward into the shale-rich facies of the Elkhorn Formation, which is overlain by the Silurian Brassfield Formation.

The C5 sequence boundary also is well exposed at the Wright Brothers Memorial, where it is placed at the base of a prominent band of bioclastic packstones traditionally placed at the top of the Whitewater Formation; these bioclastic packstones sharply overlie wavy/nodular limestones of the Whitewater Formation. The sharp upper contact of the bioclastic packstones with variegated mudstones of the Preachersville Formation is interpreted as the maximum flooding surface. The Preachersville Formation is overlain here by the Belfast Bed of the Brassfield Formation.

Throughout most of Kentucky, the C5 sequence is absent, and the Silurian Brassfield Formation overlies C4 sequence rocks. The thinning of the C5 sequence into Kentucky is probably partly the result of depositional thinning to the south and partly the result of pre-Silurian erosion. The basal contact of the Brassfield Formation characteristically displays several tens of centimeters of relief at the scale of an outcrop. In south-central Kentucky, C4 and some C3 rocks were removed by pre-Devonian erosion such that the Devonian Boyle Limestone, New Albany Shale, and Chattanooga Shale lie atop Ordovician rocks as old as the C3 sequence.

COMMENTS ON CINCINNATIAN LITHOSTRATIGRAPHIC NOMENCLATURE

TRADITIONAL STRATIGRAPHIC NOMENCLATURE

The history of Cincinnatian stratigraphic nomenclature is lengthy and has been summarized elsewhere (Cumings, 1922; Gutstadt, 1958; Weiss and Norman, 1960; Tobin, 1986). A brief summary is necessary as background to the current nomenclatural confusion. The earliest workers proposed only a few large and relatively undifferentiated units for the entire Cincinnatian Series (Orton, 1873). Subsequent workers in the late 1800's and early 1900's developed a finely subdivided nomenclature consisting of many formations and members defined on both lithologic and paleontologic criteria. This classification was summarized by Bucher and others (1939) and later published by Caster and others (1955).

The consistent expression of sequences in the type area of Cincinnatian nomenclature was largely responsible for the "layer-cake" approach of early Cincinnatian stratigraphers. However, problems arose when these units were traced out of the type area. One common nomenclatural problem arose several times as a worker would attempt to trace a formation across an unconformity—in some cases a sequence boundary, in others, a maximum flooding surface.

As facies at the bases of sequences pinch out into upramp areas of central Kentucky, these same formational names were commonly applied to dissimilar facies that occur at the top of the underlying sequence. For example, the Waynesville Formation consists of the shale-dominated facies and contains an abundant and diverse characteristic fauna. This deepest water facies of the C4 sequence pinches out into upramp areas of central Kentucky; in other words, Ordovician divers swimming southward into central Kentucky would have encountered progressively shallower water environments as they swam into upramp areas. Nonetheless, early workers confused the lithostratigraphic and chronostratigraphic nature of formations and attempted to recognize the Waynesville Formation in central Kentucky. They applied the name Waynesville Formation to a series of "unfossiliferous shales" in the same approximate stratigraphic position as the Waynesville farther north (that is, beneath the Liberty Formation). These unfossiliferous shales correspond to the bioturbated and laminated calcareous mudstone facies of the Rowland Formation. This uppermost facies of the C3 sequence pinches out northward into downramp areas; again, at the end of C3 time, a shallower set of environments would have been developed in downramp areas to the north. Early workers thus attempted to extend a formation from highstand facies above a sequence boundary/maximum flooding surface to highstand facies beneath those surfaces.

Similar problems arose with what are recognized here as transgressive facies, which have an especially narrow geographic distribution. The Saluda Formation in its type area is composed of the bioturbated and laminated carbonate mudstone facies. Near its top, it is overlain by the Hitz Bed, a thin unit of wavy-bedded wackestone with a characteristic molluscan fauna. The Saluda Formation is the uppermost facies of the C4 sequence and predictably thins to the north. The Hitz Bed is the lowermost facies of the C5 sequence and thickens predictably to the north. In this case, workers attempted to extend a formation from the highstand facies below a sequence boundary to the transgressive facies lying above the sequence boundary. However, the name Saluda has been applied to the wavy-bedded wackestone facies to the north where the type-Saluda lithology thins to a pinchout. Hence, in this paper, rocks that have been traditionally referred to the Saluda Formation but that are not type-Saluda lithology (that is, they are wavy-bedded wackestone facies) are referred to in this paper as "Saluda." The name Hitz, having priority, should be elevated to member or formation rank and be applied to these wavy-bedded wackestones of the C5 sequence.

A similar problem occurred with the Sunset Formation. In its type area near Sunset, Kentucky, the Sunset Formation is composed of wavy-bedded wackestones that belong to the transgressive systems tract of the C3 sequence. However, Foerste (1912) also applied the name Sunset Formation to the mixed packstone-shale facies that occurs northward in the same approximate stratigraphic position, below the wavy/nodular limestones of the Oregonia Formation. In this case, early workers attempted to trace a formation from transgressive facies below a maximum flooding surface to highstand facies above the surface. This mixed packstone-shale facies is not the same lithology as that of the Sunset in its type area; thus, this facies is referred to in this paper as "Sunset" to distinguish it from the type Sunset. A new formational name should be proposed for the "Sunset."

RECENT STRATIGRAPHIC NOMENCLATURE

Over time, these traditional stratigraphic units were recognized increasingly on paleontologic criteria, despite the original definitions of these units. This trend, the advent of the Stratigraphic Code, and problems arising from tracing formations across sequence boundaries fueled a re-analysis of Cincinnatian stratigraphy and the proposal of units based solely on lithology (for example, Brown and Lineback, 1966; Peck, 1966; Hatfield, 1968; Lee, 1974). Some of these units were equivalent to traditional units. For example, the Kope Formation was a redefined Eden Group. The Fairview Formation was redefined with the same name, and the Bellevue Member was elevated to formational rank. Many of the newly proposed units, such as the Dillsboro and Bull Fork Formations, were much closer in scale and lithologic variability to the original units of Orton. Many of the traditional units, however, could be redefined in purely lithologic terms (Hay, 1981; Tobin, 1982; Tobin, 1986).

Despite the Stratigraphic Code, the presence of sequences has created nomenclatural problems in the Cincinnatian Series in three ways. First, because any given facies may be overlain or underlain by another conformable facies, by a sequence boundary or by a maximum flooding surface, contact relationships of a unit are difficult to define. This is especially true at the formation scale in the geologic mapping of Kentucky. The Tate Formation, for example, rests "on the Calloway Creek Limestone; elsewhere it rests on the lower member of the Grant Lake Limestone. In southern east-central and southern central Kentucky, the Tate is overlain by the Gilbert Member of the Ashlock Formation; elsewhere it is overlain by the Grant Lake" (Weir and others, 1984, p. E43). Similarly, the Grant Lake Limestone can be defined in up to four ways. The base of the Grant Lake Limestone can be placed on the Calloway Creek Limestone, at the top of the Fairview Formation, or at the top of the Gilbert Member. The top of the Grant Lake Limestone can be placed at the base of the Rowland Formation, at the base of the "Sunset Formation," or at the base of the Corryville Formation. Contacts defined in multiple ways may therefore be isochronous where the contact coincides with a sequence boundary or maximum flooding surface or diachronous where it coincides with a facies contact.

Second, because these sequences were developed on a ramp, the local succession of facies changes geographically, and separate systems of nomenclature have arisen in different areas, characteristically defined by state lines (fig. 18-5). Ohio, Indiana, and Kentucky currently have different systems of lithostratigraphic nomenclature, Indiana particularly so (Shaver and others, 1970; Weir and others, 1984; Schumacher and others, 1991). The different systems confound stratigraphic relationships by imposing state-line boundaries across a completely gradational system of facies. Even within Kentucky, different facies successions in northern and central Kentucky have led to "vertical cut-offs" between formations that represent the same facies, such as the Clays Ferry and Fairview Formations (Weir and others, 1984). A more productive way to revise the nomenclature would be to treat the entire outcrop area as a single, genetically related body of strata, rather than to impose arbitrary political lines on a natural system. It should be noted that, wherever possible, the Ohio Division of Geological Survey has tried to extend units recognized in Kentucky into Ohio.

Third, the intertonguing of units and the thinning of units near their pinchouts promoted the lumping of facies into large homogeneous formations such as the Dillsboro and Bull Fork (fig. 18-6). These units straddle sequence boundaries and contain many dissimilar facies, making both environmental and chronostratigraphic interpretations dif-

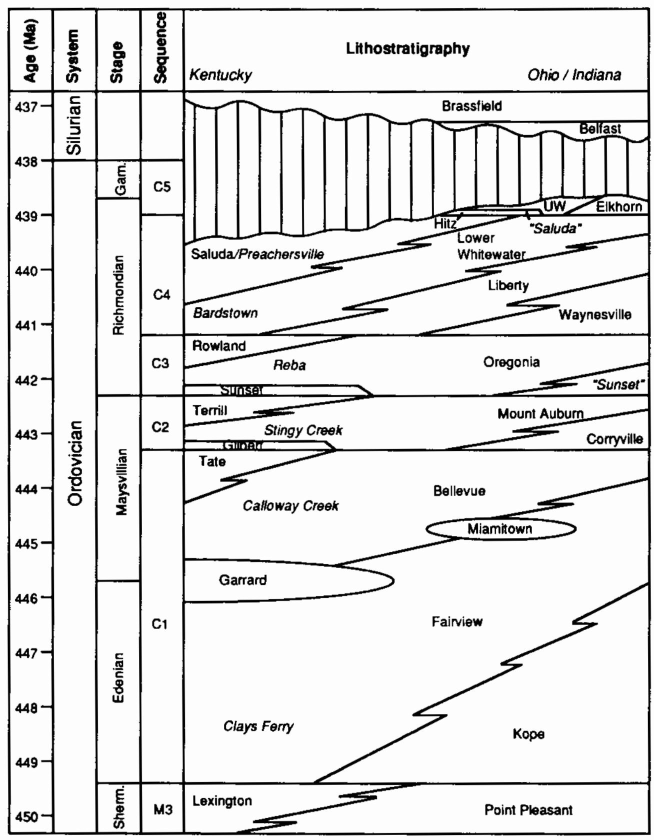

FIGURE 18-5.—Current stratigraphic terminology, particularly in Ohio and Indiana, for Upper Ordovician rocks in the Cincinnati Arch region. Most of these units refer to a single facies as recognized by Hay (1981), Tobin (1982), and Holland (1990). However, many of these facies are known by multiple stratigraphic names, the boundaries of which are placed at arbitrary vertical cutoffs. For example, The mixed packstone-shale facies of the C1 sequence is known as the Fairview Formation in Ohio and northernmost Kentucky, but as the Clays Ferry Formation in central Kentucky. Names in italics represent a name that should be abandoned on the basis of priority. "Sunset" and "Saluda" refer to stratigraphic units with lithologies unlike the original definitions of Sunset and Saluda. Although not shown on this figure, the Straight Creek Member of the Grant Lake Formation would occupy the same position as the Mt. Auburn Formation, and is regarded here as an equivalent, somewhat more calcareous variation of the Mt. Auburn Formation, similar to the distinction between Grant Lake Limestone and Grant Lake Formation (see Schumacher and others, 1991). UW = Upper Whitewater. Ma = million years.

ficult. In addition, the inconsistent boundary definitions of units such as the Grant Lake Limestone suggest many uses of the same name.

As stated previously, sequence stratigraphy is not a form of lithostratigraphy; its goal is the genetic interpretation of strata, not the recognition of mappable units. However, an understanding of sequence architecture can suggest guidelines for the naming of lithostratigraphic units. On one hand, formational contacts that straddle sequence boundaries or maximum flooding surfaces are characteristically sharp; however, because such a contact is a disconformity, one formation may overlie any of several other formations. In this case, contact definitions should emphasize the sharpness of the contact and the names of all the stratigraphic units that a formation might contact at the disconformity. On the other hand, formational contacts within systems tracts are characteristically gradational; however, the upper formation at a contact will always overlie the same lower formation. In this case, contact definitions should state the gradational yet predictable relationship between two formations.

These concepts suggest several revisions of Cincinnatian stratigraphic nomenclature (fig. 18-7):

(1) Each facies within each sequence should be named separately and given formational rank for consistency. This approach has already been done for many of the traditional units (Tobin, 1986; Schumacher and others, 1991). For the sake of consistency, the scale and variability of individual facies should be kept uniform throughout the section; in other words, if a facies can be recognized in one portion of the section, it should be similarly recognized as a distinct unit wherever it occurs in the section. As a counterexample, the shale-dominated facies of the Kope Formation is recognized as a formation by the Indiana Geological Survey, but the shale-dominated facies of the Waynesville Formation is not recognized as a distinct unit and is included within the lithologically variable Dillsboro Formation. This lack of consistency confuses geologic interpretations because it implies that the two formations represent equivalent units with which to interpret geologic history.

(2) Some units erected during the Kentucky Mapping Project should be abandoned on the basis of priority. the same facies within the same sequence was previously named (fig. 18-5). For example, the Clays Ferry Formation and the Fairview Formation refer to the same lithofacies within the same sequence, and the line between the two is drawn at an arbitrary vertical cutoff across which there is no lithologic contrast. Of these two, the Fairview Formation has priority. Similarly, both the Reba Formation and the Oregonia Formation refer to the wavy/nodular limestone facies of the

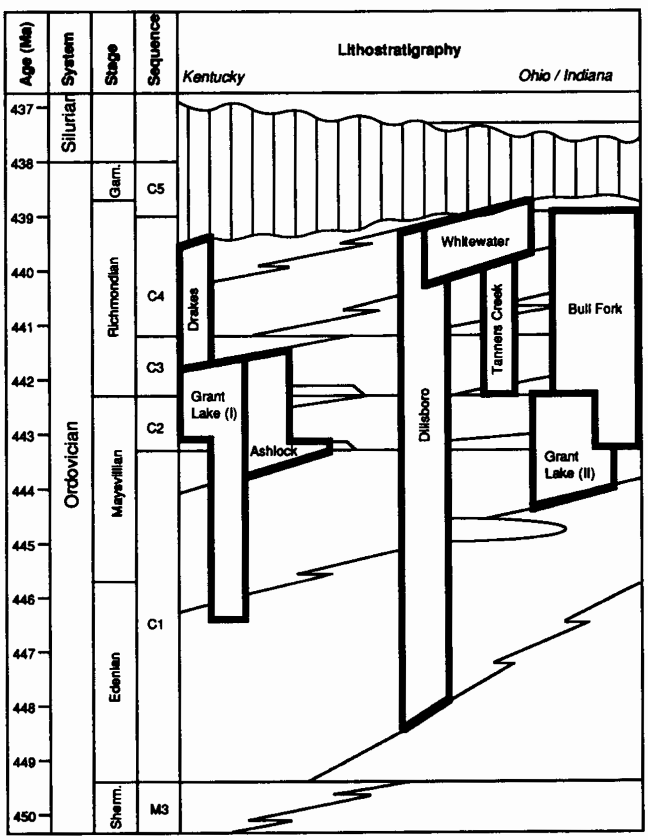

FIGURE 18-6.—Upper Ordovician stratigraphic units that lump dissimilar facies and straddle disconformities, plotted on background of figures 18-5 and 18-7. Because these units offer little interpretive value, and commonly have ill-defined or variably defined contacts, it is recommended here that their usage be abandoned. Ma = million years.

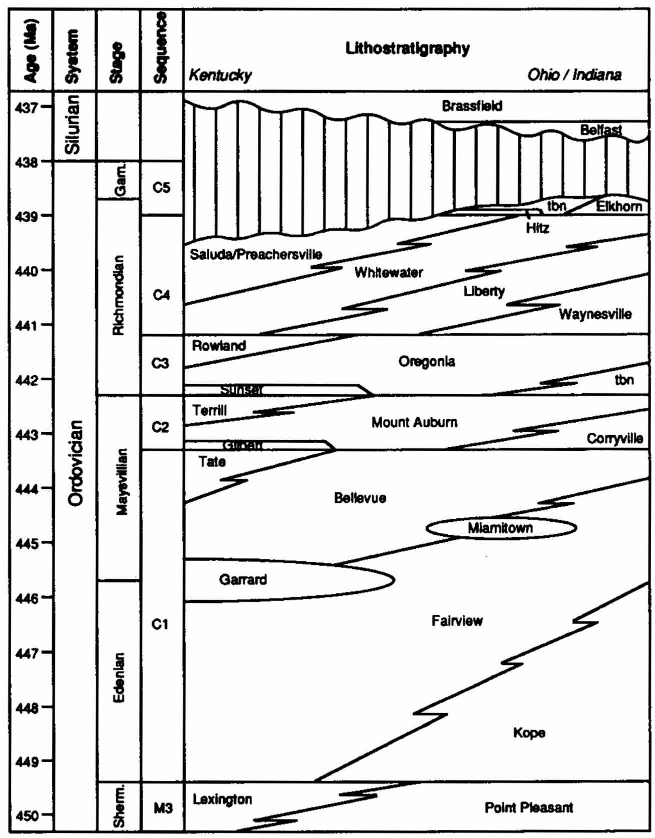

FIGURE 18-7.—Proposed stratigraphic nomenclature for the Upper Ordovician rocks of the Cincinnati Arch region. Note that each facies within each sequence (that is, a parvafacies) is given a single name; for example, contrast the current usage of Fairview and Clays Ferry Formations for a single facies with the proposed name of Fairview Formation for this facies. In this and other cases, the older name is given priority. Other similar pairs include: Bellevue and Calloway Creek, Mt. Auburn and Gilbert, Oregonia and Reba, Lower Whitewater and Bardstown, Saluda and Preachersville, and Hitz and Saluda. Also note that the "Sunset" and Upper Whitewater on figure 18-5 are labeled here as "tbn," indicating that new stratigraphic names will be proposed for these units.

C3 sequence, and their contact is an arbitrary vertical cutoff. Although the Oregonia Formation was defined both lithologically and paleontologically for much of its history, the name is long standing and has been redefined in purely lithologic terms (Tobin, 1986). The Oregonia Formation should be retained in place of the Reba Formation on the basis of priority.

(3) Some previously named units offer little interpretive value because they lump dissimilar facies and straddle sequence boundaries (fig. 18-6). With the exception of a redefined Whitewater Formation (which should be restricted to what has been traditionally called the Lower Whitewater), these units should be abandoned. For example, the Dillsboro Formation straddles three sequence boundaries and includes at least three distinct facies. Although the Dillsboro may be a recognizable mappable unit, that should not be the only goal. Lithostratigraphic units should have some interpretive value as well.

These guidelines would create a much-simplified view of Cincinnatian stratigraphy, with a return to many of the traditional names that offer real interpretive power. These guidelines also leave several units unnamed at the present, particularly within the C5 sequence (fig. 18-7). I am planning to propose names for these units following some additional field checking to establish the geographic and stratigraphic limits of these units.

It could be argued that the Stratigraphic Code insists that interpretations should not affect nomenclature and that these guidelines are therefore invalid, but this argument can be countered several ways. The Code's insistence on the lack of interpretation in the naming of a unit is a logical impossibility. The formulation of a stratigraphic code requires an implicit concept of the structure of the stratigraphic record, despite the fact that these concepts were never stated; thus, the Code itself implies a stratigraphic interpretation. Second, the Code states that lithostratigraphic units should not span known disconformities. The identification of a particular surface as a disconformity is a stratigraphic interpretation, not an observation; again, the Code is internally inconsistent because it argues that interpretation should not influence nomenclature. Finally, although sequence stratigraphy can lead to a set of lithostratigraphic guidelines, these guidelines do not necessarily imply a sequence structure to the stratigraphic record.

SUMMARY

The Cincinnatian Series consists of five stratigraphic sequences. In the type area of the Cincinnatian Series in northernmost Kentucky, southwestern Ohio, and southeastern Indiana, the sequences are dominantly shoaling upward and contain very thin transgressive intervals at their base. In upramp areas of central Kentucky, these same sequences are thinner and contain proportionally greater thicknesses of transgressive deposits. Sequence analysis of the Cincinnatian Series offers several guidelines for clarifying the current confusing lithostratigraphic nomenclature.

LOCALITIES

For more information about the individual localities that bear locality codes, please, see Appendix A in this volume.

Aiken High School (OH-HA-0012). Exposures on north side of driveway to Aiken High School on Belmont Avenue in Cincinnati, Ohio.

Ashlock Cemetery. Road cuts on U.S. Route 27, 0.8 mile (1.3 km) south of the Garrard-Lincoln County line. Lancaster, Kentucky, 7.5-minute quadrangle. Lincoln County, Kentucky. 37°34'25"N latitude, 84°36'49"W longitude.

Beckjord (OH-CT-0019). Road cuts on north side of eastbound U.S. Route 52, just west of Beckjord Coal Plant, 0.6 mile (1 km) east of Ohio Route 749.

Bedford. Road cuts on U.S. Route 42, 2.5 miles (4 km) east of intersection with U.S. Route 421 in Bedford, Kentucky. Bedford, Kentucky, 7.5-minute quadrangle. Trimble County, Kentucky. 38°36'08"N latitude, 85°16'25"W longitude.

Blue Rock Road (OH-HA-0005). Road cuts on Blue Rock Road, 0.1 mile (0.2 km) north of intersection with Cross County Highway and 0.3 mile (0.5 km) southeast of intersection with I-275.

Bon Well Hill (IN-FR-0001). Road cut at intersection of Indiana State Route 101 and Brookville Dam Road, 1 mile (1.6 km) north of Brookville, Indiana. Whitcomb (formerly Mount Carmel), Indiana, 7.5-minute quadrangle.

Brookville North. see Garr Hill.

Bybee. Road cuts on Kentucky Route 52, just east of Bybee, Kentucky. Panola, Kentucky, 7.5-minute quadrangle. Madison County, Kentucky. 37°43'13"N latitude, 84°06'43"W longitude.

Caesar Creek dam (= Caesar Creek gorge) (OH-WA-0002). Hillside outcrops on north side of tailwater area at Caesar Creek dam.

Caesar Creek spillway (OH-WA-0001). Exposures in emergency spillway of Caesar Creek Lake on Clarksville Road.

Chicken Hollow-2 (OH-BR-0001). Road cuts on south side of Chicken Hollow Road, 0.1 mile (0.2 km) east of intersection with U.S. Routes 62 and 68.

Clays Ferry. Road cuts on south side of Kentucky Route 2328 underneath south end of I-75 bridge over Kentucky River. Ford, Kentucky, 7.5-minute quadrangle. Madison County, Kentucky. 37°46'28"N latitude, 84°16'28"W longitude.

Cowan Lake (OH-CN-0001). Exposures in spillway of Cowan Lake and on north bank of Cowan Lake adjacent to spillway.

Flemingsburg. Road cuts along Kentucky Route 32, 1.8 miles (1.1 km) south of Kentucky Route 11. Flemingsburg, Kentucky, 7.5-minute quadrangle. Fleming County, Kentucky. Approximately 38°24'N latitude, 83°42'W longitude.

Frederickstown. Road cut on south side of U.S. Route 150, 0.5 mile (0.8 km) west of Nelson/Washington County line. Maud, Kentucky, 7.5-minute quadrangle. Nelson County, Kentucky. 37°46'09"N latitude, 85°21'25"W longitude.

Garr Hill (= Brookville North) (IN-FR-0003). Road cuts on opposite sides of valley along Indiana Route 101, 5.0 miles (8 km) north of Brookville, Indiana.

Georgetown (OH-BR-0006). Road cuts along Ohio Route 125 on both sides of valley of Whiteoak Creek, 0.8 mile (1.3 km) west of intersection with U.S. Route 68 in Georgetown, Ohio.

Halls Gap North. Road cuts on U.S. Route 27, 3.3 miles (5.3 km) north of intersection with Kentucky Route 643 in Halls Gap, Kentucky. Halls Gap, Kentucky, 7.5-minute quadrangle. Lincoln County, Kentucky. 37°29'52"N latitude, 84°39'00"W longitude.

Lincoln County Line. Road cuts on U.S. Route 27, 0.5 mile (0.8 km) south of Garrard-Lincoln County line and 3.5 miles

(5.6 km) south of Lancaster, Kentucky. Lancaster, Kentucky, 7.5-minute quadrangle. Lincoln County, Kentucky. 37°34'40"N latitude, 84°36'36"W longitude.

Madison #1 (= Madison South road cut) (IN-JE-0003). Road cut on east side of U.S. Route 421, 3.0 miles (4.7 km) south of intersection with Indiana Route 62 north of Madison, Indiana.

Madison #3 (= Madison North road cut) (IN-JE-0001). Road cut on east side of U.S. Route 421, 0.2-0.7 mile (0.3-1.1 km) south of intersection with Indiana Route 62 north of Madison, Indiana.

Maysville (= Maysville-Kentucky Route 11) (KY-MS-0002). Long road cut along Kentucky Route 11, 1.7 miles (2.7 km) north of intersection with Kentucky Routes 546 and 1448, just south of Maysville, Kentucky.

Muddy Creek (OH-HA-0020). Stream exposures on Muddy Creek at Muddy Creek Road bridge, 0.3 mile (0.5 km) west of Westbourne Road.

Orphanage Road (KY-KE-0003). Road cut on north side of Kentucky Route 371 (Orphanage Road), 0.4 mile (0.7 km) west of intersection with Kentucky Route 17.

Point Pleasant. Stream exposures on north side of U.S. Route 52, 0.3 mile (0.5 km) west of western city limits of Point Pleasant, Ohio. Laurel, Ohio–Kentucky, 7.5-minute quadrangle. Clermont County, Ohio. 38°54'02"N latitude, 84°14'13"W longitude.

Richmond (= Richmond-U.S. Route 27) (IN-WY-0001). Road cuts on U.S. Route 27, 0.8 mile (1.3 km) north of Farlow Road and 1.0 mile (1.6 km) south of Richmond, Indiana.

Riedlin Road/Mason Road (KY-KE-0001). Road cuts on Riedlin (Mason) Road at intersection with Kentucky Route 16, 0.4 mile (0.6 km) north of I-275.

South Gate Hill (IN-FR-0005). Road cuts on Indiana Route 1, 1.9 miles (3.0 km) south of its intersection with U.S. Route 52 at Cedar Grove, Indiana.

West Union #3 (= West Union) (OH-AD-0004).

Wright Brothers Memorial. Railroad cut on north border of Wright Brothers Memorial Park. Fairborn, Ohio, 7.5-minute quadrangle. Greene County, Ohio. 39°47'46"N latitude, 84°05'13"W longitude.

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Address of author: Steven M. Holland, Geology Department, University of Georgia, Athens, GA 30602.

APPENDIX A.—TYPE-CINCINNATIAN LOCALITIES

by
Richard Arnold Davis, Sharon C. St. Louis Diekmeyer, Lawrence I. Goldman,
Benjamin F. Dattilo, Steven M. Holland, and Roger J. Cuffey

EXPLANATION

The following list is in two parts. The first part is arranged by state and by county within each state. Within each county the localities are arranged by a code number in the format OH-HA-0002, beginning with the U.S. Postal Service code for the state. The next two letters (or, in a few cases, one letter) are the county code; it is taken from the standard county designations used nationwide in the archaeological community. The four digits refer to the specific locality within the county.

The second part is an alphabetical list by the name of the locality. In cases in which a given locality has more than one designation, the known alternatives all are listed.

Measurements are given in the format "1.0 mile (1.6 km)." The first value is in the units in which the measurement was made or published; the number in parentheses is the value converted to the other system of measurement. In this case, the actual measurement was 1.0 mile, which converts to 1.6 km. If the measurement had been stated as 1.6 km (1.0 mile), the actual measurement was 1.6 km, which converts to 1.0 mile. In the case of map distances in miles, values are given to the nearest 1/10 mile, because that is the precision of standard automobile odometers.

Some of the original surveying in this particular part of the country was done at an early enough date that the United States Land Survey System has not been applied consistently. Thus, many townships are not the 36-square-mile rectangles that they are elsewhere. Moreover, many do not bear the standard township and range designation, but, instead, have been named. What's worse, in some places there are no real townships at all. Add to that the fact that, even in the areas in which sections have been surveyed, they may not be numbered in the usual boustrophedon (alternating left to right, right to left) manner. In short, folks who are used to the regularity of locality designations west of Ohio are liable to be frustrated by the lack of such regularity in this part of the country.

The OGS numbers in the Ohio portion of this appendix refer to descriptions of measured sections on open file at the Ohio Division of Geological Survey, Columbus, Ohio.

This appendix does not have a bibliography of its own. Full references to works cited herein are listed in Appendix B of this volume, the Bibliography on the type-Cincinnatian.

LOCALITIES BY STATE AND COUNTY

INDIANA

Indiana, Dearborn County

IN-D-0001 AURORA
Road cut on U.S. Route 50 about 1 mile (1.6 km) SW of Aurora; SE$^1/_4$NE$^1/_4$NW$^1/_4$ sec. 6, T. 4 N., R. 1 W., Aurora, Indiana, 7.5-minute quadrangle; Dearborn County, Indiana
Units.—Bellevue, Fairview, Kope
References.—Anstey and Perry (1973), Hay (1977), Diekmeyer (paper 3 in this volume), Hay (paper 17 in this volume)

IN-D-0002 ST. LEON
Road cuts on north and south sides of I-74, $^1/_4$ to 1 mile east of St. Leon-Lawrenceburg exit (intersection with Indiana Route 1); sec. 13, T. 7 N., R. 2 W., Cedar Grove, Indiana, 7.5-minute quadrangle; Dearborn County, Indiana; elevation at base: 585 ft (178.3 meters)
Units.—Liberty, Waynesville
References.—Reinhart (1977), Frey (1987b, loc. 6)

IN-D-0003 TANNERS CREEK
East end of first NYC railroad cut west of Guilford; base at ball of inside rail; center S$^1/_2$ sec. 19, T. 6 N., R. 1 W., Guilford, Indiana, 7.5-minute quadrangle; Miller Twp., Dearborn County, Indiana; 39°09'55"N, 84°54'50"W; elevation at base: 545 ft (166.1 meters)
Units.—Fairview (41 ft/12.5 meters), Kope (22 ft/6.7 meters)
References.—Cumings and Galloway (1913), Weiss, Edwards, Norman, and Sharp (1965), Diekmeyer (paper 3 in this volume)

IN-D-0004 WEST HARRISON
Road cut on Pin Hook Road adjacent to I-74, 3 miles (4.8 km) west of West Harrison; NE$^1/_4$NE$^1/_4$NW$^1/_4$ sec. 16, T. 7 N., R. 1 W., Harrison, Ohio–Indiana, 7.5-minute quadrangle; Harrison Twp., Dearborn County, Indiana; 39°15'40"N, 84°51'50"W
Units.—Kope
References.—Anstey and Perry (1973), Diekmeyer (paper 3 in this volume)

IN-D-0005
Road cut on north side of I-74, 4 km (2.5 miles) west of Harrison; NE$^1/_4$NW$^1/_4$ sec. 18, T. 2 N., R. 1 E., Harrison, Ohio–Indiana, 7.5-minute quadrangle; Dearborn County, Indiana
Units.—Mt. Hope Member of Fairview Formation
References.—Giuseffi (1982, loc. 3), Frey (1987a, loc. B)

Indiana, Franklin County

IN-FR-0001 BON WELL HILL
Road cut on Indiana Route 101, 1.3-1.7 miles (2.1-2.7 km) northeast of junction with U.S. Route 52 inside north edge of Brookville; S$^1/_2$SW$^1/_4$SE$^1/_4$ sec. 16, T. 9 N., R. 2 W., Whitcomb, Indiana, 7.5-minute quadrangle (formerly Mount Carmel, Indiana, quadrangle); Franklin County, Indiana; 39°26'15"N, 84°59'25"W; 4367024 m N, 672966 m E, UTM zone 16; elevation at base: 747 ft (227.7 meters); elevation at top: 837 ft (255.1 meters)
Units.—"Brookville Fm." (Liberty, Waynesville, and "Excello" Mbrs.); in terms of the "traditional nomenclature": Liberty, Waynesville, Arnheim
References.—Hay (1977), Hay, Pope, and Frey (1981); Brandt Velbel (1985, loc. A), Frey (1987a, loc. D; 1987b, loc. 4), Hay and Cuffey (paper 10 in this volume), Hay (paper 17 in this volume), Holland (paper 18 in this volume)

IN-FR-0002 BROOKVILLE DAM SPILLWAY
Spillway below Brookville Dam, north of Brookville; SW$^1/_4$SE$^1/_4$SE$^1/_4$ sec. 17 and NW$^1/_4$NE$^1/_4$NE$^1/_4$ sec. 20, T. 9 N., R. 2 W., Brookville, Indiana, 7.5-minute quadrangle; Franklin County, Indiana; 39°26'13"N, 85°00'19"W; 4366972 m N, 671679 m E, UTM zone 16; elevation of base of spillway: 623 ft (189.9 meters) at river level in valley bottom out in front of dam
Units.—Waynesville, "Excello mbr." of "Brookville fm.," "Sta-

tion Hollow mbr." of "Brookville fm.," Bellevue, Miamitown; in terms of the "traditional nomenclature": Waynesville, Arnheim, Mt. Auburn, Corryville, Bellevue, Miamitown; Fairview and higher strata exposed in highwall opposite measured section

Note.—Across spillway from measured section is a highwall exposing 60 meters (200 ft) of Ordovician rock that correlates with strata exposed at Garr Hill (IN-FR-0003) and upper part of Bon Well Hill (IN-FR-0001). Height and steepness of this highwall make access very difficult; in any case, access is not normally permitted

References.—Hay (1977), Hay (1981), Hay, Pope, and Frey (1981), Tobin (1982), Diekmeyer (paper 3 in this volume), Hay (paper 17 in this volume), Hay and Cuffey (paper 8 in this volume)

IN-FR-0003 GARR HILL

Alternate designation.—Brookville North

Road cut on both sides of Indiana Route 101, 6.0-6.4 miles (9.6-10.2 km) northeast from junction of U.S. Route 52 and Indiana Route 101 within north edge of Brookville; E$^{1}/_{2}$SE$^{1}/_{4}$ NE$^{1}/_{4}$and E$^{1}/_{2}$NE$^{1}/_{4}$SE$^{1}/_{4}$ sec. 35, T. 10 N., R. 2 W., Whitcomb, Indiana, 7.5-minute quadrangle; Franklin County, Indiana; 39°29'11-39°29'29"N, 84°56'58"W; 4372556-4373108 m N, 676410 m E, UTM zone 16; elevation: bottom, 900 ft (274.3 meters); top, 990 ft (301.8 meters)

Units.—Basal beds of upper part of upper Whitewater, Saluda, lower Whitewater, Liberty, Liberty Mbr. of "Brookville fm."

References.—Hay (1977, p. I-18 to I-22), Hay, Pope, and Frey (1981, stop 4, p. 80, 84-86), Bliss (1984), Frey (1987a, locs. G and J), Hay and Cuffey (paper 11 in this volume), Hay (paper 17 in this volume), Holland (paper 18 in this volume)

IN-FR-0004 FAIRFIELD CAUSEWAY

Alternate designations.—Causeway Road, Fairfield Road

Cuts along Fairfield Road, which runs west from Indiana Route 101, passes near village of New Fairfield, and traverses causeway between north and south parts of Brookville Reservoir; causeway is in sec. 28, T. 10 N., R. 2 W., New Fairfield, Indiana, 7.5-minute quadrangle; Fairfield Twp., Franklin County, Indiana; road cut at west end of causeway is in sec. 28, but Everton, Indiana, 7.5-minute quadrangle; center of causeway is at 39°30'23"N, 84°59'43"W

Units.—Liberty, Waynesville

IN-FR-0005 SOUTH GATE HILL

Alternate designation.—Indiana Route 1; Cedar Grove

Road cuts on both sides of Indiana Route 1, 1.0-1.5 miles (1.6-2.4 km) north of crossroads at village of South Gate and 1.9-2.4 miles (3.0-3.8 km) south of intersection of Indiana Route 1 with U.S. Route 52 at Cedar Grove; W$^{1}/_{2}$W$^{1}/_{2}$SE$^{1}/_{4}$ sec. 23, T. 8 N., R. 2 W., Cedar Grove, Indiana, 7.5-minute quadrangle; Franklin County, Indiana; 39°20'08-39°20'30"N, 84°57'20-84°57'24"W; 4355853-4356469 m N, 676098-676194 m E, UTM zone 16; elevation at base: 750 ft (228.6 meters)

Units.—Saluda, lower Whitewater, "Brookville formation" (including Liberty Member, Waynesville Shale Member, and "Excello member"); in terms of "traditional nomenclature": Saluda, lower Whitewater, Liberty, Waynesville, Oregonia Mbr. of Arnheim Fm.

References.—Kirchner (1991), Hay, Kirchner, and Cuffey (paper 12 in this volume), Hay (paper 17 in this volume), Holland (paper 18 in this volume)

IN-FR-0006

Small stream-bank exposures along Whistle Creek where Whistle Creek Road crosses stream, north side of road; center sec. 4, T. 11 N., R. 12 E., Metamora, Indiana, 7.5-minute quadrangle; Franklin County, Indiana

Units.—"trilobite shale unit," Waynesville

References.—Frey (1987b, loc. 5)

Indiana, Jefferson County

IN-JE-0001 MADISON NORTH ROAD CUT

Alternate designation.—Madison #3 (Holland)

Road cut along U.S. Route 421 0.2-0.7 mile (0.3-1.1 km) south of intersection with Indiana Route 62; massive Saluda Dolomite is nicely exposed 0.5 mile (0.8 km) south of intersection; SW corner sec. 13 and NW$^{1}/_{4}$NW$^{1}/_{4}$and center NW$^{1}/_{4}$ sec. 24, T. 4 N., R. 10 E., Canaan, Indiana, 7.5-minute quadrangle; Jefferson County, Indiana; 38°46'45"N, 85°21'58"W (Saluda exposure); 4293308 m N, 641928 m E, UTM zone 16 (Saluda exposure)

Units.—Silurian, Whitewater, Saluda, Liberty

References.—Totten and Hay (1987, North Road Cut, A in Fig. 1), Hay, Totten, and Cuffey (paper 6 in this volume), Hay (paper 17 in this volume), Holland (paper 18 in this volume)

IN-JE-0002 MADISON MIDDLE ROAD CUT

Road cut along U.S. Route 421 beginning about 1.1-1.2 miles (1.8-1.9 km) south of intersection with Indiana Route 62; center SW$^{1}/_{4}$ sec. 24, T. 4 N., R. 10 E., Canaan, Indiana, 7.5-minute quadrangle; Jefferson County, Indiana

Units.—"Excello member" of "Brookville formation"

References.—Totten and Hay (1987, Middle Road Cut, B in Fig. 1), Hay, Totten, and Cuffey (paper 6 in this volume), Hay (paper 17 in this volume)

IN-JE-0003 MADISON SOUTH ROAD CUT

Alternate designation.—Madison #1 (Holland)

Road cut along U.S. Route 421 beginning about 3.0 miles (4.7 km) south of intersection with Indiana Route 62 and ending about 0.5 mile (0.8 km) north of Madison; center W$^{1}/_{2}$ NE$^{1}/_{4}$ sec. 35, T. 4 N., R. 10 E., Madison West, Indiana–Kentucky, 7.5-minute quadrangle; Jefferson County, Indiana; 38°44'58"N, 85°22'35"W

Units.—"Excello mbr." of "Brookville fm.," Bellevue

References.—Totten and Hay (1987, South Road Cut, C in Fig. 1), Holland (1990), Diekmeyer (paper 3 in this volume), Hay, Totten, and Cuffey (paper 6 in this volume), Hay (paper 17 in this volume); Holland (paper 18 in this volume)

IN-JE-0004 MADISON-INDIANA ROUTE 56

Four closely spaced road cuts along Indiana Route 56 (formerly also Indiana Route 62) 0.3-1.2 miles (0.5-1.9 km) east (downgrade) from junction with present Indiana Route 62 about 4 miles west of downtown Madison; most conspicuous cut is highwall exposing Saluda Dolomite at sharp curve 0.5-0.6 mile (0.8-1.0 km) east of that junction; NE corner sec. 6 and N$^{1}/_{2}$N$^{1}/_{2}$NW$^{1}/_{4}$ sec. 5, T. 3 N., and S$^{1}/_{2}$SW$^{1}/_{4}$SE$^{1}/_{4}$ sec. 31, T. 4 N., R. 10 E., Madison West, Indiana–Kentucky, 7.5-minute quadrangle; Jefferson County, Indiana; 38°44'12"N, 85°26'28"W (high cut through Saluda); 4288480 m N, 635461 m E, UTM zone 16 (high cut through Saluda)

Units.—upper Whitewater, Saluda, Liberty, Waynesville, Arnheim

References.—Hattin, Nosow, Perkins, Stumm, Mound, and Utgaard (1961, stop 8, p. 328-331, 343-347); Hattin and Cuffey (paper 14 in this volume)

IN-JE-0005 MADISON-RILEY CREEK

Low outcrop on west bank of dry creek (Riley Creek, although name is not on topographic quadrangle) along west side of trailer park on northwest side of historic Madison (down on valley floor near Ohio River); center SW$^{1}/_{4}$NW$^{1}/_{4}$SE$^{1}/_{4}$ sec. 34, T. 4 N., R. 10 E., Madison West, Indiana–Kentucky, 7.5-minute quadrangle; Jefferson County, Indiana; 38°44'36"N, 85°23'42"W; 4289290 m N, 639478 m E, UTM zone 16

Units.—Bellevue (*Monticulipora molesta* bed)

References.—Patton, Perry, and Wayne (1953, stop 12, p. 26); Dively and Cuffey (1994)

IN-JE-0006 MADISON-HANGING ROCK

Road cuts along east side of Indiana Route 7, 0.8-1.2 miles

(1.3-1.9 km) north of junction with Indiana Route 56 on west side of downtown Madison; Saluda Dolomite forms ledges of small waterfall at sharp bend in road 1.0 mile (1.6 km) north of that junction, ascending out of Ohio River valley; NW$^1/_4$NE$^1/_4$ sec. 34, T. 4 N., R. 10 E., Clifty Falls, Indiana, 7.5-minute quadrangle; Jefferson County, Indiana; 38°45'04"N, 85°23'40"W (Saluda waterfall); 4290186 m N, 639510 m E, UTM zone 16
Units.—Silurian, "Upper Whitewater," Saluda, Liberty
References.—Patton, Perry, and Wayne (1953, stop 12, p. 26-27); Butler & Cuffey (1994, 1996)

Indiana, Ohio County

IN-O-0001 RISING SUN
Bank of Indiana Route 56, 2 miles (3.2 km) SW of Rising Sun; base in culvert; incomplete exposure; center SE$^1/_4$SW$^1/_4$ sec. 16, T. 3 N., R.1 W., Aberdeen, Indiana–Kentucky, 7.5-minute quadrangle; Randolph Twp., Ohio County, Indiana; 38°55'20"N, 84°53'00"W; elevation at base: 630 ft (192.0 meters)
Units.—Fairview, Bellevue, Kope (52 ft/15.8 meters to base of Maysvillian)
References.—Weiss, Edwards, Norman, and Sharp (1965), Diekmeyer (paper 3 in this volume)
OGS measured section no. 14809

IN-O-0002 ARNOLD CREEK
Stream exposures in tributary of Arnold Creek, 4.7 km (2.9 miles) west of Rising Sun, near intersection of White Road and Indiana Route 262; extending from NE$^1/_4$NE$^1/_4$SE$^1/_4$ to NW$^1/_4$SE$^1/_4$NE$^1/_4$ sec. 12, T. 3 N., R. 2 W., Aberdeen, Indiana–Kentucky, 7.5-minute quadrangle; Randolph Twp., Ohio County, Indiana; 38°56'15"N, 84°55'55"W
Units.—Kope
References.—Anstey and Perry (1973), Diekmeyer (paper 3 in this volume)

Indiana, Switzerland County

IN-SW-0001 WILEY BRANCH
Stream exposures in Wiley Branch about 0.5 km (0.3 mile) east of Florence; NE$^1/_4$SE$^1/_4$NE$^1/_4$ sec. 32 to NE$^1/_4$NW$^1/_4$NW$^1/_4$ sec. 33, T. 2 N., R. 1 W., Florence, Indiana–Kentucky, 7.5-minute quadrangle; Switzerland County, Indiana; 38°47'53"N, 84°53'34"W
Units.—Kope
References.—Anstey and Perry (1973), Diekmeyer (paper 3 in this volume)

Indiana, Wayne County

IN-WY-0001 RICHMOND-U.S. ROUTE 27
Large road cut on U.S. Route 27, 1.2-1.3 miles (1.9-2.1 km) southwest of junction with Indiana Route 227 on south edge of Richmond; NW$^1/_4$SE$^1/_4$SW$^1/_4$ sec. 17, T. 13 N., R. 1 W., Richmond, Indiana, 7.5-minute quadrangle; Wayne Twp., Wayne County, Indiana; 39°47'13"N, 84°54'10"W; 4406000 m N, 679610 m E, UTM zone 16
Units.—Whitewater
References.—Hay, 1977; Frey (1987a, loc. H), Holland (paper 18 in this volume), Hay (paper 17 in this volume), Hay and Cuffey (paper 15 in this volume)

IN-WY-0002 SHORT CREEK/STRAIGHT LINE PIKE
Small road cut and adjacent stream cut where Straight Line Pike (Road) crosses Short Creek, 1.0 mile (1.6 km) south of the U.S. 27-Indiana Route 227 junction, Richmond; center E edge SE$^1/_4$ sec. 17, T. 13 N., R. 1 W., Richmond, Indiana, 7.5-minute quadrangle; Wayne Twp., Wayne County, Indiana
Units.—Whitewater
References.—Hay and Cuffey (paper 15 in this volume)

IN-WY-0003 SIM HODGIN PARKWAY
Road cut along Sim Hodgin Parkway in Whitewater Gorge through Richmond, Indiana, Wayne County, Indiana
Units.—Whitewater and/or Elkhorn
References.—Hay and Cuffey (paper 15 in this volume)

IN-WY-0004 ELKHORN FALLS
Waterfalls just west of Indiana Route 227 at bridge over Elkhorn Creek (just north of intersection of Indiana Route 227 and Niewohner Road); this site is at east end of Elkhorn Creek locality (IN-WY-0008); SW$^1/_4$SE$^1/_4$NW$^1/_4$ sec. 22, T. 13 N., R. 1 W., New Paris, Ohio–Indiana, 7.5-minute quadrangle; Boston Twp., Wayne County, Indiana; NOTE: this is private property; the owner is adamant about trespassing!
Units.—Brassfield, Elkhorn (apparently)
References.—Hay and Cuffey (paper 15 in this volume)

IN-WY-0005 SUB RUN
Exposure at intersection of Indiana Route 121 and Pottershop/ Abington/Liberty Road $^1/_8$ mile (0.2 km) southeast of Abington; SE$^1/_4$ sec. 2, T. 12 N., R. 2 W., Liberty, Indiana, 7.5-minute quadrangle; Wayne County, Indiana; NOTE: this is private property; obtain permission before visiting site
Units.—Liberty Member of "Brookville formation," Whitewater Formation
References.—Hay and Cuffey (paper 15 in this volume)

IN-WY-0006 THISTLETHWAITE FALLS
Waterfalls on Waterfall Road, west from U.S. Route 27 North (at first traffic light north of hospital); Thistlethwaite Falls is at northern termination of Whitewater Gorge on West Fork of East Fork Whitewater River; NW$^1/_4$SW$^1/_4$SE$^1/_4$ sec. 29, T. 14 N., R. 1 W., Richmond, Indiana, 7.5-minute quadrangle; Wayne Twp., Wayne County, Indiana
Units.—Whitewater
References.—Hay and Cuffey (paper 15 in this volume)

IN-WY-0007 MIDDLEFORK RESERVOIR
Outcrop at spillway of reservoir, on Reservoir Road (Cart Road) north of Richmond and east of U.S. Route 27 (turn is north of hospital and north of Waterfall Road); NE$^1/_4$ sec. 28, T. 14 N., R. 1 W., Richmond, Indiana, 7.5-minute quadrangle; Wayne Twp., Wayne County, Indiana; NOTE: property belongs to Indiana-American Water Company
Units.—Whitewater
References.—Hay and Cuffey (paper 15 in this volume)

IN-WY-0008 ELKHORN CREEK
Stream cuts and stream bed between Straight Line Road (Pike) and Indiana Route 227; most of section, including Elkhorn Shale, is exposed between Straight Line Road and Fouts Road; east end of this stretch of creek is Elkhorn Falls (IN-WY-0004); S$^1/_2$ sec. 21, T. 13 N., R. 1 W. and SW$^1/_4$ sec. 22, T. 13 N., R. 1 W., Richmond, Indiana, and New Paris, Ohio–Indiana, 7.5-minute quadrangles; Boston Twp., Wayne County, Indiana; NOTE: this is private property; get permission beforehand
Units.—Elkhorn, Whitewater
References.—Hay and Cuffey (paper 15 in this volume)

KENTUCKY

Kentucky, Boone County

KY-BE-0001 MALL ROAD
Exposure at south end of Mall Road in Florence, in area now occupied by a shopping plaza; Union, Kentucky, 7.5-minute quadrangle; Boone County, Kentucky
Units.—Bull Fork, Corryville
References.—Meyer and others (1981, first of two entries labeled "stop 5," p. 58-62), Meyer (1990, p. 156)

KY-BE-0002 RABBIT HASH
Road cut on Boone County Road 536 beginning at community of Rabbit Hash and extending about 0.3 mile (0.5 km) east; Rising Sun, Kentucky–Indiana, 7.5-minute quadrangle; Boone County, Kentucky; Carter Coordinates: 20-DD-56, 426.72-1,005.84 m east of west line, 944.88 m south of north line; 38°56'40"N, 84°50'50"W
Units.—Kope
References.—Anstey and Perry (1973), Diekmeyer (paper 3 in this volume)

KY-BE-0003 LAWRENCEBURG
Road cuts on either side of I-275 in Kentucky, 0.7 km (0.4 mile) south of Ohio River across from Lawrenceburg, Indiana; Lawrenceburg, Indiana–Kentucky–Ohio, 7.5-minute quadrangle; Boone County, Kentucky; 39°05'46"N, 84°49'04"W; 4329508 N, 688721 E, UTM zone 16
Units.—Corryville (?), Bellevue, Miamitown, Fairview, Kope
References.—Dattilo (paper 7 in this volume)

Kentucky, Bracken County

KY-BK-0001 BRADFORD
Road cut on Kentucky Route 8 west of Little Snag Creek, 0.25 mile (0.40 km) west of Bradford; Moscow, Ohio–Kentucky, 7.5-minute quadrangle; Bracken County, Kentucky; 38°47'10"N, 84°09'00"W; elevation at base: 504 ft (153.6 meters)
Units.—Point Pleasant (63 ft/19.2 meters); base of Kope estimated by Weiss, Edwards, Norman, and Sharp (1965) to be about 15 ft (4.6 meters) above top of section exposed
References.—Weiss, Edwards, Norman, and Sharp (1965), Harrison (1981 *in* Meyer and others, 1981, stop 1, p. 34, 35, 36), Diekmeyer (paper 3 in this volume)
OGS measured section no. 14932

KY-BK-0002 MELDAHL DAM
Road cut on south side of Kentucky Route 8 about 1.8 miles (2.9 km) west of Meldahl Dam; Moscow, Ohio–Kentucky, 7.5-minute quadrangle; Bracken County, Kentucky
Units.—Kope, Point Pleasant
References.—Harrison (1981, *in* Meyer and others, 1981, stop 2, p. 34, 35, 36)

KY-BK-0003 FOSTER
Bank along Kentucky Route 8 about 0.2 mile (0.3 km) northwest of Foster, starting 8.3 ft (2.53 meters) above end of bridge; Moscow, Ohio–Kentucky, 7.5-minute quadrangle; Bracken County, Kentucky; 38°48'15"N, 84°13'15"W; elevation at base: 512 ft (156.1 meters)
Units.—Kope (10 ft/3.0 meters + another 50 ft/15.2 meters poorly exposed above that), Point Pleasant (60 ft/18.3 meters)
References.—Weiss, Edwards, Norman, and Sharp (1965), Diekmeyer (paper 3 in this volume); see also Foerste (1905, p. 151)
OGS measured section no. 14937

Kentucky, Campbell County

KY-CP-0001 FORT THOMAS
Alternate designations.—445/8 road cut; I-275 East/Kentucky Route 445; Brent
Composite section of two groups of exposures: 1—road cut at intersection of Kentucky Route 8 and Kentucky Route 445; 2—on north side of I-275 just west of Ohio River; Newport, Kentucky–Ohio, 7.5-minute quadrangle; Campbell County, Kentucky; 39°03'15"N, 84°26'00"W
Units.—Kope (59 meters/193.6 ft); Jennette (1986): Fairview (7.2 meters/23.6 ft), Kope (21.3 meters/69.9 ft)
References.—Harrison and Mahan (1981, *in* Meyer and others, 1981, stop 3, p. 36-45), Tobin (1982), Hoge (1985), Jennette (1986), Diekmeyer (paper 3 in this volume)

KY-CP-0002 NEWPORT SHOPPING CENTER
Alternate designation.—"Newport" (Weiss, Edwards, Norman, and Sharp, 1965)
Cut behind Newport Shopping Center on U.S. Route 27 (Monmouth St./Alexandria Pike) at south edge of Newport, northeast of intersection with Carothers Road; Newport, Kentucky–Ohio, 7.5-minute quadrangle; Campbell County, Kentucky; 39°04'50"N, 84°28'45"W; elevation at base: 575 ft (175.3 meters)
Units.—base of Maysvillian, Kope (164 ft/50.0 meters)
References.—Weiss, Edwards, Norman, and Sharp (1965), Diekmeyer (paper 3 in this volume)

KY-CP-0003 SOUTHGATE
Alternate designation.—I-471/U.S. Route 27
Road cuts on both sides of I-471 at intersection with U.S. Route 27 (interchange 2), E of Southgate; Newport, Kentucky–Ohio, 7.5-minute quadrangle; Campbell County, Kentucky; 39°04'00"N, 84°27'50"W
Units.—Fairview (0.5 meter/1.6 ft), Kope (23.2 meters/76.1 ft)
References.—Jennette (1986), Diekmeyer (paper 3 in this volume)

KY-CP-0004 NEWPORT-GRAND AVENUE
Alternate designation.—I-471/Grand Avenue
Outcrops on west side of I-471 at Grand Avenue, Newport (interchange 4 on quad map); Newport, Kentucky–Ohio, 7.5-minute quadrangle; Campbell County, Kentucky; 39°04'45"N, 84°28'05"W
Units.—Fairview (2.9 meters/9.5 ft), Kope (26 meters/85.3 ft)
References.—Jennette (1986), Diekmeyer (paper 3 in this volume)

KY-CP-0005 JOHNS HILL
Alternate designation.—I-275/Kentucky Route 9
Road cuts on both sides of I-275, 1/4 mile (0.4 km) east of interchange with Kentucky Route 9, on flank of Johns Hill; Newport, Kentucky–Ohio, 7.5-minute quadrangle; Campbell County, Kentucky; 39°02'35"N, 84°28'40"W
Units.—Fairview (8.0 meters/26.2 ft), Kope (8.7 meters/28.5 ft)
References.—Jennette (1986), Diekmeyer (paper 3 in this volume)

Kentucky, Gallatin County

KY-GA-0001 SUGAR CREEK
Two exposures: 1—road cut on U.S. Route 42 500 ft (152.4 meters) west of bridge over Sugar Creek; 2—stream exposures in gully ascending hillside, immediately south of U.S. Route 42, about 1 mile (1.6 km) west of bridge over Sugar Creek; Patriot, Kentucky–Indiana, 7.5-minute quadrangle; Gallatin County, Kentucky; Carter Coordinates: 1: 71-BB-57, 1400 ft (426.7 m) east of west line, 200 ft (61.0 m) south of north line; 2: 16-BB-57, 1700 ft (518.2 m) east of west line, 1500 ft (457.2 m) south of north line; 38°47'00"N, 84°48'46"W
Units.—Kope, Lexington Limestone
References.—Anstey and Fowler (1969, localities 4 and 7), Anstey and Fowler (1972), Diekmeyer (paper 3 in this volume)

Kentucky, Kenton County

KY-KE-0001 RIEDLIN ROAD/MASON ROAD
Road cuts along both sides of Riedlin Road/Mason Road, at intersection with and east of Kentucky Route 16 (Taylor Mill Road); intersection is 0.4 mile (0.6 km) north of I-275 (exit 79); Covington, Kentucky–Ohio, 7.5-minute quadrangle (Luft, 1971; Ford, 1974); Kenton County, Kentucky; 39°01'15"N, 84°30'30"W

Units.—Bellevue (4.5 meters/14.7 ft), Miamitown (1.0 meter/ 3.3 ft), Fairview (32.6 meters/107 ft), Kope (8.5 meters/27.9 ft)
References.—Tobin and Pryor (1981, *in* Meyer and others, 1981, stop 4), Tobin (1982, 1986), Davis (1986), Jennette (1986), Frey (1987a, loc. C), Holland (1990), Diekmeyer (1990, 1992, paper 3 in this volume), Dattilo (paper 7 in this volume), Holland (paper 18 in this volume)

KY-KE-0002 THOMAS MORE PARKWAY
Series of small cuts behind "Chancellor Center" office-condominium on Thomas More Parkway, 1.0 km (0.6 mile) east of intersection with Turkeyfoot Road; this site, when cut in 1989, contained three broad benches bounded by 2- to 3-meter (6-to 10-ft), west-facing exposures. Covington, Kentucky–Ohio, 7.5-minute quadrangle (Luft, 1971; Ford, 1974); Kenton County, Kentucky; 39°01'20"N, 84°33'57"W
Units.—Corryville, possibly Bellevue
References.—Goldman (paper 9 in this volume)

KY-KE-0003 ORPHANAGE ROAD
Road cut on north side of Kentucky Route 371 (Orphanage Rd.), 0.4 mile (0.6 km) west of intersection with Kentucky Route 17; Covington, Kentucky–Ohio, 7.5-minute quadrangle (Luft, 1971; Ford, 1974); Kenton County, Kentucky; 39°01'47"N, 84°32'30"W
Units.—Kope (30 meters/98.4 ft)
References.—Frey (1987a, loc. A), Holland (1990, paper 18 in this volume), Diekmeyer (paper 3 in this volume)

KY-KE-0004 COVINGTON
Alternate designation.—I-75/Covington
Cuts along I-75/I-71 0.8 mile (1.3 km) north of interchange with Kentucky Route 1072 (Kyles Lane) (NOTE: since 1992, I-75/I-71 has been slightly re-routed in this stretch); Covington, Kentucky–Ohio, 7.5-minute quadrangle (Luft, 1971; Ford, 1974); Kenton County, Kentucky; 39°03'45"N, 84°31'30"W
Units.—Fairview (3 meters/9.8 ft), Kope (30.5 meters/100.1 ft); Jennette (1986): Fairview (0.3 meter/1.0 ft), Kope (23.3 meters/76.4 ft)
References.—Tobin (1982), Jennette (1986), Diekmeyer (paper 3 in this volume)

KY-KE-0005 I-275/TURKEYFOOT ROAD
Road cut on I-275 east at Turkeyfoot Road (Exit 2); Covington, Kentucky–Ohio, 7.5-minute quadrangle (Luft, 1971; Ford, 1974); Kenton County, Kentucky; 39°01'20"N, 84°34'00"W
Units.—Fairview (0.7 meter/2.3 ft), Kope (12.5 meters/41.0 ft)
References.—Jennette (1986), Diekmeyer (paper 3 in this volume)

KY-KE-0006 WAYNE ROAD
Alternate designation.—Devou Park
Hill above picnic area west of Wayne Road on northwest corner of Prisoner's Lake, in Devou Park in Covington; Covington, Kentucky–Ohio, 7.5-minute quadrangle (Luft, 1971; Ford, 1974); Kenton County, Kentucky; 39°05'00"N, 84°32'14"W; 4328712 N, 713048 E, UTM zone 16
Units.—lower Bellevue, Miamitown, upper Fairview
References.—Dattilo (paper 7 in this volume)

Kentucky, Lewis County

KY-LW-0001 CABIN CREEK
Road cut on both sides of Kentucky Route 10 about 2 miles (3.2 km) east of Tollesboro; Tollesboro, Kentucky, 7.5-minute quadrangle; Lewis County, Kentucky; Carter Coordinate section 3-Y-72
Units.—Brassfield, Preachersville Member of Drakes
References.—Potter and others (1991, stop 2C)

Kentucky, Mason County

KY-MS-0002 MAYSVILLE-KENTUCKY ROUTE 11
Alternate designation.—Maysville (Holland)
Composite section of seven road cuts along Kentucky Route 11 for 2 miles (3.2 km) north of intersection with Kentucky Route 546 (AA Highway), just south of Maysville; Mays Lick, Kentucky, 7.5-minute quadrangle; Mason County, Kentucky; approximately 38°37'N, 83°45'W; Carter Coordinate section 20-Z-69
Units.—Grant Lake, Fairview, Kope
References.—Potter and others (1991, stop 10); Holland (paper 18 in this volume)
OGS measured section no. 16914

KY-MS-0003 SOUTH LICK BRANCH
Two road cuts along Kentucky Route 546 (AA Highway) near its intersection with Kentucky Route 1449 and where Route 546 crosses Stone Lick Branch; Orangeburg, Kentucky, 7.5-minute quadrangle; Mason County, Kentucky; Carter Coordinate sections 22-Z-70 and 23-Z-70
Units.—lower half of Bull Fork (equivalent to Arnheim)
References.—Potter and others (1991, stops 1a and 1b)

KY-MS-0004 MAYSVILLE-U.S. ROUTES 62 & 68
Road cuts along U.S. Routes 62 and 68 just south of Maysville, 0.8 mile (1.3 km) from south end of Maysville-Aberdeen Bridge; Maysville West, Ohio–Kentucky, 7.5-minute quadrangle; Mason County, Kentucky; 38°38'25"N, 83°46'00"W; elevation at base: 162 meters (531 ft)
Units.—Bellevue (22.6 meters/74.1 ft), Fairmount Member of Fairview Formation (21.6 meters/70.9 ft), Mt. Hope Member of Fairview Formation (40.8 meters/133.9 ft), Kope; this locality is one of three co-equal type sections of the Kope Formation (other two are OH-BR-0003 and OH-BR-0004)
References.—Weiss and Sweet (1964), Diekmeyer (paper 3 in this volume)

KY-MS-0005 SLEEPY HOLLOW
Road cut on Kentucky Route 1449, about 6.4 km (4.0 miles) north-northwest of Orangeburg; Orangeburg, Kentucky, 7.5-minute quadrangle; Mason County, Kentucky; 38°37'10"N, 83°42'51"W
Units.—Bull Fork, Grant Lake Limestone (including Corryville Member), Fairview. This locality is the type section of Grant Lake Limestone
References.—Peck (1966), Lee (1974), Diekmeyer (paper 3 in this volume), Goldman (paper 9 in this volume)

KY-MS-0006 MAYSVILLE BRYOZOAN REEF MOUNDS
Road cut on west side of U.S. Route 68, 0.1 mile (0.2 km) south of junction of U.S. Route 68 and U.S. Route 62 at south edge of village of Washington; Mays Lick, Kentucky, 7.5-minute quadrangle (Gibbons, 1968); Mason County, Kentucky; 38°36'36"N, 83°48'39"W; 4277049 m N, 255255 m E, UTM zone 17 (Note: road widened and mounds destroyed between 1992 and 1998.)
Units.—upper member of Grant Lake Limestone (Corryville and Mt. Auburn equivalents)
References.—Cuffey (paper 5 in this volume)

OHIO

Ohio, Adams County

OH-AD-0002 WEST FORK OHIO BRUSH CREEK
Road cut on south side of Ohio Route 32 approximately 2 miles (3.2 km) east of intersection of Ohio Routes 32 and 246; Seaman, Ohio, 7.5-minute quadrangle; Scott Twp., Adams County, Ohio

Units.—Brassfield, Preachersville Member of Drakes Formation, Bull Fork

References.—Schumacher, Shrake, Swinford, Brockman, and Wickstrom (1987, "stop 1," p. 39, 46, 47)

OH-AD-0003 MANCHESTER

Exposure on west-facing hill on east side of Ohio Route 136 near intersection of Route 136 and Brown Hill Road, approximately 1.5 miles (2.4 km) north of Manchester; this road cut is within a few hundred meters of the Isaacs Creek exposure of Sweet (1979a, p. G23, loc. 25). Manchester Islands, Kentucky–Ohio, 7.5-minute quadrangle; Sprigg Twp., Adams County, Ohio; 38°44'07"N, 83°03'09"W

Units.—Bull Fork, Corryville

References.—Lee (1974), Goldman (paper 9 in this volume), Hay (paper 17 in this volume)

OH-AD-0004 WEST UNION

Alternate designation.—West Union #3 (Holland, paper 18 in this volume)

Road cut on west side of Ohio Route 41, 3.2 miles (5.1 km) northeast from intersection with Ohio Route 247 in West Union; West Union, Ohio, 7.5-minute quadrangle; Tiffin Twp., Adams County, Ohio; 38°49'38"N, 83°30'20"W

Units.—Silurian, Elkhorn, Whitewater

References.—Holland (paper 18 in this volume)

Ohio, Brown County

OH-BR-0001 CHICKEN HOLLOW

Two localities: 1—road cut west of U.S. Routes 68 and 62 just north of intersection with Chicken Hollow Road; 2—road cuts on south side of Chicken Hollow Road, 0.1 mile (0.2 km) east of intersection with U.S. Route 62 and 68; Russellville, Ohio–Kentucky, 7.5-minute quadrangle; Union Twp., Brown County, Ohio; 38°46'14"N, 83°48'14"W (at no. 2)

Units.—Grant Lake, Bellevue, Fairview

References.—1: Schumacher, Shrake, Swinford, Brockman, and Wickstrom (1987, stop 2, p. 40, 46, 48, 49, 50); 2: Holland (paper 18 in this volume)

OH-BR-0002 RIPLEY

Along U.S. Routes 68 and 62, 0.2 mile (0.3 km) northeast of intersection with U.S. Route 52; Maysville West, Kentucky–Ohio, 7.5-minute quadrangle; Brown County, Ohio

Units.—Kope

References.—Schumacher, Shrake, Swinford, Brockman, and Wickstrom (1987, stop 3, p. 40, 46, 48-50)

OH-BR-0003 KOPE HOLLOW

Exposures in Kope Hollow, starting about 0.5 km (0.3 mile) east of Levanna, north of U.S. Route 52; mostly Russellville, Ohio–Kentucky, 7.5-minute quadrangle, but also Higginsport, Ohio–Kentucky, 7.5-minute quadrangle; Union Twp., Brown County, Ohio; 38°46'00"N, 83°52'40"W; elevation of base: 151 meters (495 ft), in culvert under U.S. Route 52

Units.—Kope (151 ft/46.0 meters), Point Pleasant (32 ft/9.8 meters); this locality is one of three co-equal type sections of the Kope Formation (other two are KY-MS-0004 and OH-BR-0004)

References.—Weiss and Sweet (1964), Weiss, Edwards, Norman, and Sharp (1965), Diekmeyer (paper 3 in this volume)

OGS measured section no. 13100

OH-BR-0004 RED OAK CREEK

Stream cut 3.2 km (2 miles) north of Ripley; Russellville, Ohio–Kentucky, 7.5-minute quadrangle; Union Twp., Brown County, Ohio; 38°45'40"N, 83°49'30"W; elevation of base: 175 meters (574 ft)

Units.—Fairview, Kope; this locality is one of three co-equal type sections of the Kope Formation (other two are KY-MS-0004 and OH-BR-0003)

References.—Weiss and Sweet (1964); Diekmeyer (paper 3 in this volume)

OH-BR-0005 EAGLE CREEK

Exposures on unnamed tributary of West Fork Eagle Creek, about 415 meters (1,700 ft) south of junction of Ohio Route 125 and Dr. Faul Road; Russellville, Ohio–Kentucky, 7.5-minute quadrangle; Jefferson Twp., Brown County, Ohio; 38°51'02"N, 83°45'10"W; elevation at base (stream level): 795 ft (242.4 meters)

Units.—Straight Creek (a Mt. Auburn equivalent; 5.5 meters/18.0 ft), Corryville (3.4 meters/11.2 ft)

References.—Goldman (paper 9 in this volume)

OGS measured section no. 16912

OH-BR-0006 GEORGETOWN

Road cuts along both sides of Ohio Route 125 on both sides of White Oak Creek valley, 0.8 mile (1.3 km) west of intersection with U.S. Route 68 in Georgetown; Hamersville, Ohio, and Higginsport, Ohio–Kentucky, 7.5-minute quadrangles; Lewis Twp., Brown County, Ohio; 38°52'33"N, 83°55'53"W

Units.—Bull Fork, Grant Lake (28.8 meters/94.4 ft), Bellevue (14.8 meters/48.6 ft), Fairview (9.2 meters/30.2 ft); Kope exposed in the banks of White Oak Creek south of Ohio Route 125 (Pleasant Twp., 38°52'10"N, 83°55'00"W) and in a road cut on Ohio Route 125 about 0.5 mile (0.8 km) west of city limits of Georgetown (Pleasant Twp., 38°52'15"N, 83°55'00"W)

References.—Lee (1974), Tobin (1982), Holland (1990), Diekmeyer (paper 3 in this volume), Goldman (paper 9 in this volume), Holland (paper 18 in this volume)

OH-BR-0007 GOOSE RUN

Exposure along stream 91 meters (300 ft) west of White Oak Station Road on Goose Run; Hamersville, Ohio, 7.5-minute quadrangle; Scott Twp., Brown County, Ohio; 38°58'47"N, 83°53'38"W

Units.—Straight Creek/Mt. Auburn, Corryville

References.—Goldman (paper 9 in this volume)

OGS measured section no. 16906

OH-BR-0008 RIPLEY #2

Road cut 2.5 miles (4.0 km) north of city limits of Ripley, along west side of U.S. Routes 62/68; Russellville, Ohio–Kentucky, 7.5-minute quadrangle; Union Twp., Brown County, Ohio; 38°46'30"N, 83°49'08"W

Units.—Grant Lake (19.7 meters/64.4 ft), Fairview

References.—Lee (1974), Goldman (paper 9 in this volume), Hay (paper 17 in this volume)

OH-BR-0009 WHITE OAK CREEK

Stream cut along White Oak Creek, approximately 300 meters (1,000 ft) north of New Hope; Hamersville, Ohio, 7.5-minute quadrangle; Scott Twp., Brown County, Ohio; 38°57'57"N, 83°54'36"W; elevation at base (stream level): approximately 860 ft (262 meters)

Units.—Corryville (6.5 meters/21.3 ft)

References.—Goldman (paper 9 in this volume)

OGS measured section no. 16910

OH-BR-0010 WHITE SWAN RUN

Exposures along unnamed creek running south into White Oak Creek near mouth of Cochran Run; Higginsport, Ohio–Kentucky, 7.5-minute quadrangle; Lewis Twp., Brown County, Ohio; 38°50'15"N, 83°56'30"W; elevation at base: 555 ft (169.2 meters)

Units.—Kope (161 ft/49.1 meters), to base of Maysvillian
References.—Weiss, Edwards, Norman, and Sharp (1965), Diekmeyer (paper 3 in this volume)
OGS measured section no. 13108

Ohio, Butler County

OH-BU-0001 ARMCO STEEL
Hill and road cut on Armco Steel Company property in Middletown; on line between secs. 19 and 13, T. 2, R. 4, Trenton, Ohio, 7.5-minute quadrangle; Butler County, Ohio; elevation: 680-730 ft (207.3-222.5 meters)
Units.—Mt. Auburn (40 ft/12.2 meters), Corryville (10 ft/3.05 meters)
References.—Reinhart (1977a, p. I-35 to I-36, stop 5)

OH-BU-0002 MAUD CUT
Alternate designation.—"Big 4" railroad cut
Exposures along railroad line between Maud and West Chester, east of I-75 viaduct over railroad line and northeast of intersection of I-75 (exit 21) and Cincinnati-Dayton Road (map: Pope and Martin, 1977, page before p. I-1); Glendale, Ohio, 7.5-minute quadrangle; Union Twp., Butler County, Ohio; 39°20'25"N, 84°23'30"W; NOTE: This exposure is difficult to reach because of lack of local paths or roads that lead to tracks. It is also dangerous because the line is active, and trains move through briskly. Do not trespass on railroad property
Units.—Arnheim, Mt. Auburn, Corryville (section: Reinhart, 1977a, p. I-38)
References.—Reinhart (1977a, p. I-37 to I-38, stop 6), Goldman (paper 9 in this volume)

OH-BU-0003 ELK CREEK
Stream exposure along east bank of Elk Creek at first meander bend, 460 meters (1,500 ft) north of Howe Road bridge; Middletown, Ohio, 7.5-minute quadrangle; Madison Twp., Butler County, Ohio; 39°30'20"N, 84°27'36"W
Units.—Corryville (5.5 meters/18.0 ft)
References.—Goldman (paper 9 in this volume)
OGS measured section no. 16893

OH-BU-0004 HUNTS CREEK
Exposure along Hunts Creek, 460 meters (1,500 ft) west of junction of Princeton and Yankee Roads; exposure begins at intersection of a south-flowing stream and Hunts Creek and continues upstream as a series of low cuts on alternating sides of creek; Trenton, Ohio, 7.5-minute quadrangle; Liberty Twp., Butler County, Ohio; 39°23'25"N; 84°23'25"W
Units.—Mt. Auburn (1.3 meters/4.3 ft), Corryville (7.4 meters/ 24.2 ft)
References.—Goldman (paper 9 in this volume)
OGS measured section no. 16889

OH-BU-0005 MIDDLETOWN
Alternate designation.—"Excello" locality (Hay, 1981)
Road cuts along both sides of Ohio Route 4, just south of bridge across Dicks Creek, about 0.5 km (0.3 mile) south of junction with Ohio Route 73; Trenton, Ohio, 7.5-minute quadrangle; Lemon Twp., Butler County, Ohio; 39°28'40"N, 84°24'58"W
Units.—Mt. Auburn, Corryville; this locality is type section of Hay's (1981) "Excello member" of "Brookville formation"
References.—Hay (1981), Tobin (1982), Goldman (paper 9 in this volume)

OH-BU-0006 WEST MIDDLETOWN
Exposure along unnamed northern tributary of unnamed stream situated 152 meters (500 ft) north of driveway on west side of Trenton-Franklin Road; driveway is 0.8 km (0.5 mile) north of West Middletown; Middletown, Ohio, 7.5-minute quadrangle; Madison Twp., Butler County, Ohio; 39°31'55"N, 84°25'05"W
Units.—Mt. Auburn (5.2 meters/17.1 ft), Corryville (5.0 meters/ 16.4 ft)
References.—Goldman (paper 9 in this volume)
OGS measured section no. 16885

OH-BU-0007
Stream-bank exposures on south side of Collins (Bull) Run, at Pfieffer Park, just south of Miami University campus; center SE$^1/_4$, sec. 27, T. 5 N., R. 1 E., Millville, Ohio, 7.5-minute quadrangle; Oxford Twp., Butler County, Ohio
Units.—"trilobite shale unit," Waynesville
References.—Frey (1987b, loc. 7)

Ohio, Clermont County

OH-CT-0001 BATAVIA #1
Road cut along exit ramp from Ohio Route 32 to Ohio Route 132, 0.5 km (0.3 mile) east of East Fork Little Miami River; Batavia, Ohio, 7.5-minute quadrangle; Batavia Twp., Clermont County, Ohio; 39°05'15"N, 84°10'15"W
Units.—Kope
References.—Hay, Pope, and Frey (1981, stop 1, p. 80-81), Tobin (1982), Meyer and others (1985), Shrake, Schumacher, and Swinford (1988, stop 1-A, p. 31-35, 37), Diekmeyer (paper 3 in this volume)

OH-CT-0002 BATAVIA #2
Road cuts at top of hill on both sides of Ohio Route 32 about 1.2 km (0.7 mile) east of intersection of Ohio Routes 132/ 222 and Ohio Route 32, east of Batavia; Batavia, Ohio, 7.5-minute quadrangle; Batavia Twp., Clermont County, Ohio; 39°05'10"N, 84°09'55"W
Units.—Bellevue (7.9 meters/25.9 ft), Miamitown (0.9-1.2 meters/3.0-3.9 ft), Fairview (12.1 meters/39.7 ft)
References.—Lee (1974), Hay, Pope, and Frey (1981, stop 2, p. 81-82), Shrake, Schumacher, and Swinford (1988, stop 1-B, p. 31, 32, 35-38), Diekmeyer (paper 3 in this volume), Goldman (paper 9 in this volume)

OH-CT-0004 STONELICK CREEK
Stream cuts along Stonelick Creek upstream and downstream from Ohio Route 131 bridge; Newtonsville, Ohio, plus a bit of the Goshen, Ohio, 7.5-minute quadrangles; Stonelick Twp., Clermont County, Ohio; 39°10'40"N, 84°06'43"W (at Ohio Route 131 bridge)
Units.—Mt. Auburn, Corryville, Bellevue, Fairview; proposed neotype section for Corryville Member of Grant Lake Formation (Schumacher, Swinford, and Shrake, 1991) is part of these Stonelick Creek exposures
References.—Meyer, Osgood, Hinterlong, and Tobin (1981, *in* Meyer and others, 1981, stop 6), Pojeta (1982, 1987), Schumacher (1984), Brandt Velbel (1985, loc. C), Schumacher, Swinford, and Shrake (1991), Diekmeyer (paper 3 in this volume), Goldman (paper 9 in this volume)
OGS measured section nos. 16836, 16837,16838, 16847, 16848, 16852

OH-CT-0005 WILLIAM LIGHT PAVING COMPANY QUARRY
Abandoned quarry south of Indian Creek, 0.25 mile (0.4 km) east of junction of Ohio Route 232 and Big Indian Road; this intersection is 1.5 miles (2.4 km) east of U.S. Route 52 at Point Pleasant; Laurel, Ohio–Kentucky, 7.5-minute quadrangle; Clermont County, Ohio; 38°53'17"N, 84°12'13"W
Units.—Kope, Point Pleasant
References.—Schumacher, Shrake, Swinford, Brockman, and Wickstrom (1987, stop 4, p. 41, 50-52)

OH-CT-0006 BACKBONE CREEK
Stream cuts along Backbone Creek, 0.27 mile (0.43 km) east of Ohio Route 32 entrance ramp onto Ohio Route 132; Batavia, Ohio, 7.5-minute quadrangle; Batavia Twp., Cler-

mont County, Ohio; 39°05'20"N, 84°10'10"W
Units.—Corryville, Bellevue (8 meters/26.2 ft), Fairview (30 meters/98.4 ft), Kope (30 meters/98.4 ft)
References.—Meyer, Schumacher, Swinford, Jennette, and Brockman (1985), Jennette (1986), Kepferle, Noger, Meyer, and Schumacher (1987), Diekmeyer (paper 3 in this volume)

OH-CT-0007 EAST FORK RESERVOIR SPILLWAY/WM. A. HARSHA LAKE
Emergency overflow spillway of East Fork Reservoir (= Wm. A. Harsha Lake); spillway is reached via Slade Road, off Ohio Route 222, 1.2 km (0.7 mile) north of intersection with Ohio Route 125; Batavia, Ohio, 7.5-minute quadrangle; Batavia Twp., Clermont County, Ohio; 39°01'34"N, 84°09'30"W
Units.—Grant Lake, upper Fairview
References.—Diekmeyer (paper 3 in this volume)

OH-CT-0008 O'BANNON CREEK
Gully along east-facing stream exposure 365 meters (1,200 ft) south of Gaynor Farm Road bridge; Goshen, Ohio, 7.5-minute quadrangle; Goshen Twp., Clermont County, Ohio; 39°14'07"N, 84°11'03"W
Units.—Corryville, Bellevue
References.—Goldman (paper 3 in this volume)
OGS measured section no. 16834

OH-CT-0009 TODD RUN
Stream cut 60 meters (200 ft) west of Ohio Route 133 bridge, which is 0.8 mile (1.3 km) south of junction of Ohio Routes 133 and 32; Williamsburg, Ohio, 7.5-minute quadrangle; Williamsburg Twp., Clermont County, Ohio; 39°02'23"N, 84°02'38"W
Units.—Corryville
References.—Goldman (paper 9 in this volume)
OGS measured section no. 16853

OH-CT-0010 BEAR CREEK
Quarry on east side of Bear Creek, adjacent to U.S. Route 52; Moscow, Ohio–Kentucky, 7.5-minute quadrangle; Washington Twp., Clermont County, Ohio; 38°48'00"N, 84°09'20"W; elevation: 497 ft (151.5 meters)
Units.—Eden (70 ft/21.3 meters), Point Pleasant (69 ft/21 meters, basal 12 ft/3.7 meters covered)
References.—Weiss, Edwards, Norman, and Sharp (1965), Diekmeyer (paper 3 in this volume)

OH-CT-0011 BOAT RUN
Stream exposures above Clermontville Road bridge (at east edge of New Richmond 7.5-minute quadrangle) and up left fork toward Mt. Zion Church; Laurel, Ohio–Kentucky, 7.5-minute quadrangle; Monroe Twp., Clermont County, Ohio; 38°55'25"N, 84°14'30"W; elevation at base: 488 ft (149 meters)
Units.—Kope (72 ft/21.9 meters), Point Pleasant (52 ft/15.8 meters)
References.—Weiss, Edwards, Norman, and Sharp (1965), Diekmeyer (paper 3 in this volume)
OGS measured section no. 14934

OH-CT-0012 CHILO
Stream exposures along creek parallel to Ohio Route 222, 0.2 mile (0.32 km) from U.S. Route 52; Moscow, Ohio–Kentucky, 7.5-minute quadrangle; Franklin Twp., Clermont County, Ohio; 38°47'45"N, 84°08'15"W; elevation at base: 590 ft (179.8 meters)
Units.—Kope (30 ft/9.1 meters), Point Pleasant (11 ft/3.4 meters)
References.—Weiss, Edwards, Norman, and Sharp (1965); Diekmeyer (paper 3 in this volume)
OGS measured section no. 13098

OH-CT-0013 HAPPY HOLLOW
Stream exposures in Happy Hollow between U.S. Route 50 and Ohio Route 28 east of Milford; Madeira, Ohio, 7.5-minute quadrangle; Miami Twp., Clermont County, Ohio; 39°10'45"N, 84°16'00"W; elevation at base: 558 ft (170.1 meters)
Units.—Weiss, Edwards, Norman, and Sharp (1965): Kope (87 ft/26.5 meters) from below middle bridge to base of Maysville; Jennette (1986): Kope (16.25 meters/53.3 ft), Fairview (1.0 meter/3.3 ft)
References.—Weiss, Edwards, Norman, and Sharp (1965); Jennette (1986); Diekmeyer (paper 3 in this volume)
OGS measured section no. 13105

OH-CT-0014 INDIAN CREEK
Composite section consisting of a 21-ft (6.4-meter) cutbank at junction of North Fork with Indian Creek and an upper 59 ft (18.0 meters) beginning below Ohio Route 743 bridge over Indian Creek; Laurel, Ohio–Kentucky, and Moscow, Ohio–Kentucky, 7.5-minute quadrangles; Washington Twp., Clermont County, Ohio; part 1: 38°53'20"N, 84°10'42"W; part 2: 38°52'15"N, 84°09'40"W; elevation at base: 622 ft (189.6 meters)
Units.—part 1 is lower Kope; part 2, which may overlap part 1, is middle Kope
References.—Weiss, Edwards, Norman, and Sharp (1965); Diekmeyer (paper 3 in this volume)
OGS measured section nos. 13097 (parts 1 and 2), 13112 (part 2)

OH-CT-0015 NINEMILE CREEK
Two exposures: 1—upper exposure along creek from bridge at fork of Ninemile-Tobasco Road and Bradbury [Bradburg on quad] Road 1.75 miles (2.8 km) SSW of Withamsville, Ohio; 2—cutbank on lower Ninemile Creek opposite junction of Ninemile-Tobasco Road and Nordyke Road; Withamsville, Ohio–Kentucky, 7.5-minute quadrangle; Pierce Twp., Clermont County, Ohio; 1: 39°02'30"N, 84°17'30"W; 2: 39°02'10"N, 84°18'30"W; elevation at base: 1 = 575 ft (175.3 meters); 2 = 490 ft (149.4 meters)
Units.—1: Kope (154 ft/46.9 meters to base of Maysville); 2: lower Kope (31 ft/9.4 meters, overlaps upper exposure by about 8 ft/2.4 meters)
References.—Weiss, Edwards, Norman, and Sharp (1965); Diekmeyer (paper 3 in this volume)
OGS measured section nos. 13094 (2), 13138 (1)

OH-CT-0016 NORTH POINT PLEASANT
Unnamed ravine 0.3 mile (0.5 km) northwest of Opossum Hollow, 1.1 miles (1.7 km) west from Point Pleasant; base adjacent to U.S. Route 52; Laurel, Ohio–Kentucky, 7.5-minute quadrangle; Monroe Twp., Clermont County, Ohio; 38°54'25"N, 84°14'35"W; elevation at base: 505 ft (153.9 meters)
Units.—Kope (65 ft/19.8 meters), Point Pleasant (53 ft/16.2 meters)
References.—Weiss, Edwards, Norman, and Sharp (1965); Diekmeyer (paper 3 in this volume); see also Foerste (1905, p. 151)
OGS measured section no. 13096

OH-CT-0017 SLICKAWAY RUN
Stream exposures along creek from Cedron to Felicity beginning with lowest rock in run; Felicity, Ohio–Kentucky, 7.5-minute quadrangle; Franklin Twp., Clermont County, Ohio; 39°48'15"N to 39°49'45"N, 84°03'00"W to 84°04'50"W; elevation at base: 551 ft (167.9 meters)
Units.—Kope (171 ft/52.1 meters), Point Pleasant (4 ft/1.2 meters); upper Point Pleasant also exposed on Bullskin Creek below mouth of Slickaway Run
References.—Weiss, Edwards, Norman, and Sharp (1965); Diekmeyer (paper 3 in this volume)
OGS measured section no. 13099

OH-CT-0018 TWELVEMILE CREEK

Stream exposures along creek beginning at bridge of Ohio Route 132 where Fagin Run branches to the north; New Richmond, Kentucky–Ohio, and Laurel, Ohio–Kentucky, 7.5-minute quadrangles; Ohio Twp., Clermont County, Ohio; 38°58'00"N, 84°15'40"W; elevation at base: 496.5 ft (151.3 meters)

Units.—Kope (108.5 ft/33.1 meters), Point Pleasant (6.5 ft/2.0 meters)

References.—Weiss, Edwards, Norman, and Sharp (1965)

OGS measured section no. 13095

OH-CT-0019 BECKJORD

Road cuts on north side of eastbound U.S. Route 52, just west of Beckjord Coal Plant, 0.6 mile (1 km) east of Ohio Route 749; Withamsville, Ohio–Kentucky, 7.5-minute quadrangle; Clermont County, Ohio; 39°00'07"N, 84°17'49"W

Units.—Kope, Point Pleasant

References.—Holland (paper 18 in this volume)

OH-CT-0020 POINT PLEASANT

Stream exposures on north side of U.S. Route 52, 0.3 mile (0.5 km) west of western city limits of Point Pleasant; Laurel, Ohio–Kentucky, 7.5-minute quadrangle; Clermont County, Ohio; 38°54'02"N, 84°14'13"W

Units.—Kope, Point Pleasant

References.—Holland (paper 18 in this volume)

Ohio, Clinton County

OH-CN-0001 COWAN LAKE

Exposures in spillway of Cowan Lake and on north bank of lake adjacent to spillway; Clarksville, Ohio, 7.5-minute quadrangle; Vernon Twp., Clinton County, Ohio; 39°23'22"N, 83°55'38"W

Units.—Whitewater, Liberty, Bull Fork

References.—Frey (1987a, loc. I), Holland (paper 18 in this volume)

OH-CN-0002

Stream-bank exposures along Stony Hollow, just north of Todds Fork, immediately north of Clarksville; Clarksville, Ohio, 7.5-minute quadrangle; Vernon Twp., Clinton County, Ohio; 39°24'30"N, 83°59'25"W

Units.—"*Treptoceras duseri* shale unit," Waynesville

References.—Frey (1987b, loc. 3)

Ohio, Greene County

OH-GR-0001

Road cut on west side of U.S. Route 68, 0.6 km (0.4 mile) south of Goes Station; Yellow Springs, Ohio, 7.5-minute quadrangle; Greene County, Ohio.; 39°45'30"N, 83°55'30"W

Units.—Preachersville Member of Drakes

References.—Frey (1987a, loc. K)

Ohio, Hamilton County

OH-HA-0001 FAIRVIEW PARK

Exposure in city park, reached via a one-way drive off McMillan Street west of intersection with Ravine Street; drive debouches into Ravine Street just south of intersection with Warner Street; city of Cincinnati, Cincinnati West, Ohio, and Covington, Kentucky–Ohio, 7.5-minute quadrangles (Luft, 1971; Ford, 1974); Hamilton County, Ohio; 39°07'30"N, 84°31'50"W

Units.—Bellevue, Miamitown, Fairview; name of Fairview Formation was taken from this locality

References.—Diekmeyer (paper 3 in this volume)

OH-HA-0002 EMMING STREET

Road cut (old quarry face) on north side of Emming Street, west of Clifton Avenue, between Wheeler and Stratford, and just below the transmitting tower; sec. 19, city of Cincinnati, Covington, Kentucky–Ohio, 7.5-minute quadrangle (Luft, 1971, Ford, 1974); Hamilton County, Ohio; 39°07'22"N, 84°31'21"W

Units.—Corryville, Bellevue, Miamitown, Fairview

References.—Diekmeyer (paper 3 in this volume), Dattilo (paper 7 in this volume), Goldman (paper 9 in this volume)

OH-HA-0003 BELLEVUE HILL

Alternate designation.—Clifton Hill (Ford, 1967)

Exposure between top of cliff in Bellevue Hill Park and Clifton Avenue; sec. 13, city of Cincinnati, Covington, Kentucky–Ohio, 7.5-minute quadrangle (Luft, 1971; Ford, 1974); Hamilton County, Ohio; 39°07'17"N, 84°31'14"W; elevation at base: 645 ft (196.6 meters); NOTE: steep (not for children or the clumsy)

Units.—Corryville, Bellevue (22 ft/6.7 meters), Miamitown (5 ft/1.5 meters), Fairview (108 ft/32.9 meters), Kope (37 ft/11.3 meters). NOTE: Bellevue Limestone was named for the Bellevue House, a drinking establishment that was located on the hilltop above this exposure. This exposure is Ford's (1967) neotype section for Fairview Formation. The Bellevue-Corryville contact is set at a prominent limestone bed that forms a small ledge near the cliff edge

References.—Ford (1967), Diekmeyer (paper 3 in this volume), Dattilo (paper 7 in this volume), Goldman (paper 9 in this volume)

OH-HA-0004 RICE AND GAGE STREETS

Alternate designation.—Christ Hospital

Road cut at intersection of Rice and Gage Streets, Cincinnati, on grounds of Christ Hospital, under hospital heliport; opposite 2227 Gage Street, Cincinnati, Ohio; this locality is on a spur of the hill called Mount Auburn; the Jackson Hill Park locality (OH-HA-0018) is situated on the next spur to the south; sec. 13, Fractional R. 2, T. 3, city of Cincinnati, Covington, Kentucky–Ohio, 7.5-minute quadrangle (Luft, 1971; Ford, 1974); Hamilton County, Ohio; 39°07'15"N, 84°30'50"W; 4332909 N, 714976 E, UTM zone 16; elevation at base: 663 ft (202.1 meters). NOTE: because this locality is on the grounds of Christ Hospital, permission must be obtained from the hospital before this site is visited, or security guards will help you complete your visit in a prompt manner

Units.—Bellevue, Miamitown, Fairview; this exposure was designated the neotype section of the Bellevue Limestone by Ford (1967)

References.—Ford (1965, 1967), Diekmeyer (paper 3 in this volume), Dattilo (paper 7 in this volume)

OGS measured section no. 15372

OH-HA-0005 BLUE ROCK ROAD

Road cut 0.3 mile (0.5 km) southeast of junction of I-275 (Exit 31) and Blue Rock Road; just north of exit ramp from the Cross County Highway; Colerain Twp., T. 2, R. 1, Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Hamilton County, Ohio; 39°13'47"N, 84°37'16"W

Units.—Sunset, Mt. Auburn, Corryville (mostly buried, at base of cut); measured section in Krumpolz (1980, p. 170-175)

References.—Ford (1967), Krumpolz (1980, loc. 1), Meyer, Krumpolz, & Tobin (1981, *in* Meyer and others, 1981, stop 7, p. 68-70), Tobin (1982), Rassman (1984), Schumacher (1984), Meyer (1990), Goldman (paper 9 in this volume), Holland (paper 18 in this volume)

OH-HA-0006 GRAND AVENUE

East-facing cliff (quarry) just west of Grand Avenue, Cincinnati (opposite 2196 Grand Avenue); near center of north edge of topographic sheet; city of Cincinnati, Covington, Kentucky–Ohio, 7.5-minute quadrangle (Ford, 1974); Hamilton County, Ohio; 39°07'10'N, 84°33'20"W; elevation at base: 585

ft (178.3 meters)
Units.—Kope (94 ft/28.7 meters from quarry floor to Maysville); type section of Grand Avenue Member of Kope
References.—Weiss, Edwards, Norman, and Sharp (1965), Ford (1967), Diekmeyer (paper 3 in this volume)
OGS measured section no. 13277

OH-HA-0007 HARRISON
Road cut on Marvin Road on north side of I-74 at New Biddinger Road; sec. 18, T. 2 N., R. 1 E., Harrison, Ohio–Indiana, 7.5-minute quadrangle; Harrison Twp., Hamilton County, Ohio
Units.—Fairmount and Mt. Hope Members of Fairview
References.—Reinhart (1977a, stop 7, p. I-40)

OH-HA-0008 MIAMITOWN WEST
Alternate designation.—"H'way cuts W. of Miamitown" (Ford, 1967, fig. 6, p. 926)
Originally a road cut on I-74 about 1 mile (1.6 km) west of Miamitown, Ohio; subsequently an interchange between I-74 and I-275 was constructed at the location; locality consists of six road cuts surrounding the various interchange roads; the measured section "highway cuts west of Miamitown" of Ford (1967, fig. 10) was a composite that ran essentially all the way from this locality to that designed herein as "Miamitown/Hamilton-Cleves exit" (OH-HA-0009); sec. 35, Addyston, Ohio–Kentucky, 7.5-minute quadrangle (Ford, 1972); Whitewater Twp., Hamilton County, Ohio; 39°13'14"N, 84°44'10"W; 4343499 N, 695446 E, UTM zone 16. NOTE: as with all interstate highway cuts, permission from the Ohio Department of Transportation is required to stop at this site
Units.—Miamitown, Fairview (including North Bend Tongue), Kope (including Grand Avenue Member and Wesselman Tongue); this locality is the type section of the Miamitown Shale
References.—Ford (1965, 1967), Dattilo (paper 7 in this volume)

OH-HA-0009 MIAMITOWN/HAMILTON-CLEVES EXIT
Road cut on exit ramp from I-74/I-275 east, leading to U.S. Route 52/Ohio Route 128 (Hamilton-Cleves Road), 0.8 mile (1.3 km) SSW of crossroads in center of Miamitown; the measured section "highway cuts west of Miamitown" of Ford (1967) was a composite that ran essentially all the way from this locality to that designed herein as "Miamitown West" (OH-HA-0008); center SE$^1/_4$SE$^1/_4$ sec. 1, T. 1 N., R. 1 E., Addyston, Ohio–Kentucky 7.5-minute quadrangle (Ford, 1972); Whitewater Twp., Hamilton County, Ohio; 39°12'21"N, 84°42'39"W; 4341928 m N, 697649 m E, UTM zone 16; elevation at base: 550 ft (167.6 meters)
Units.—Grand Avenue Member and Wesselman Tongue of Kope; Jennette (1986): Fairview (0.2 meter/0.7 ft), Kope or McMicken (19.9 meters/65.3 ft)
References.—Ford (1965, 1967), Jennette (1986), Diekmeyer (paper 3 in this volume), Cuffey (paper 4 in this volume)
OGS measured section no. 15378

OH-HA-0010 NORTH BEND
South-facing bank of a southwest-flowing stream slightly more than 1 mile (1.6 km) ENE of North Bend; Miami Twp., Addyston, Ohio–Kentucky, 7.5-minute quadrangle (Ford, 1972); Hamilton County, Ohio; 39°09'15"N, 84°44'00"W; elevation: 618-630 ft (188-192 meters)
Units.—North Bend Tongue of Fairview; this locality is the type section of the North Bend Tongue
References.—Ford (1965; 1967, p. 929); Diekmeyer (paper 3 in this volume)

OH-HA-0011 WESSELMAN
East-facing embankment of an unnamed creek that is followed by Wesselman Road, about 400 ft (122 meters) south of Zion Hill Road; NE$^1/_4$NE$^1/_4$NE$^1/_4$ sec. 4, Addyston, Ohio–Kentucky, 7.5-minute quadrangle (Ford, 1972); Miami and Green Twps., Hamilton County, Ohio; between 39°10'45"N and 39°12'30"N, and 84°40'45"W and 84°41'15"W
Units.—Wesselman Tongue of Kope, bounded above and below by rock of the Fairview; this locality is the type section of the Wesselman Tongue
References.—Ford (1965; 1967, p. 928), Diekmeyer (paper 3 in this volume)

OH-HA-0012 AIKEN SCHOOL
Alternate designation.—Aiken High School
Composite of three sites: 1—north cut of athletic field of Aiken High School (sec. 30); 2—excavation west of school on Belmont Avenue (sec. 30); 3—excavation at Hammond North Apartments, east of Hamilton Avenue (sec. 29); secs. 29 and 30, Fractional R. 2, T. 3, city of Cincinnati, Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Hamilton County, Ohio; 39°11'33"N, 84°32'58"W; elevation: at base of 1, 735 ft (224.0 meters); at base of 2, 854 ft (260.3 meters); at base of 3, 813 ft (247.8 meters)
Units.—Bellevue (23 ft/7.0 meters), Miamitown (5 ft/1.5 meters), Fairview (26 ft/7.9 meters)
References.—Ford (1965; 1967, p. 919, 927), Tobin (1982), Diekmeyer (paper 3 in this volume), Holland (paper 18 in this volume)
OGS measured section nos. 15375 (1), 15456 (3), 15457 (2) (originally all three measured sections were no. 15375)

OH-HA-0013 BALD KNOB
Hill in Cincinnati, Ohio; quarry west of State Avenue; road cut 0.9 mile (1.5 km) west of intersection of State Avenue and Lehman Road; Covington, Kentucky–Ohio 7.5-minute quadrangle (Luft, 1971; Ford, 1974); Hamilton County, Ohio; 39°06'00"N, 84°33'05"W; elevation at base: 630 ft (192 meters). NOTE: prior to the 1930's Bald Knob was taller than it now is; the top was removed to provide fill material for the site of Cincinnati's Union Terminal, in order to bring that site above flood stage
Units.—Weiss, Edwards, Norman, and Sharp (1965): 22 ft (6.7 meters) from toe of south end of bluff to base of Maysvillian; Ford (1967, fig. 6): Miamitown, Fairview, and Kope (including Grand Avenue Member); Jennette (1986): Fairview (9.7 meters/31.8 ft), Kope (7.6 meters/24.9 ft)
References.—Weiss, Edwards, Norman, and Sharp (1965), Ford (1967), Sweet (1979), Tobin (1982), Jennette (1986), Diekmeyer (paper 3 in this volume)
OGS measured section nos. 14807, 14808

OH-HA-0014 BRIARLY CREEK
Stream cut of Briarly Creek, from creek bed to top of southeast bank, southeast of bend in Sheed Road; sec. 30, Fractional R. 2, T. 2, Addyston, Ohio–Kentucky, 7.5-minute quadrangle (Ford, 1972); Green Twp., Hamilton County, Ohio; 39°12'20"N, 84°38'45"W; elevation of base: 602 ft (183.5 meters)
Units.—Miamitown, Fairview, Wesselman Tongue of Kope (5 ft/1.5 meters), North Bend Tongue of Fairview (11 ft/3.4 meters), other Kope (19 ft/5.8 meters)
References.—Ford (1965, 1967), Diekmeyer (paper 3 in this volume)
OGS measured section no. 15382

OH-HA-0015 CAMP CLAYBANKS
Cliff opposite Camp Claybanks, by spillway on West Fork Mill Creek; sec. 17, R. 1, T. 3, Glendale, Ohio, 7.5-minute quadrangle; Hamilton County, Ohio; elevation of base: 624 ft (190.2 meters); 39°15'35"N, 84°29'30"W
Units.—Bellevue (3 ft/0.9 meter), Miamitown (8 ft/2.4 meters), Fairview (84 ft/25.6 meters), Kope (12 ft/3.7 meters)
References.—Ford (1965, 1967), Diekmeyer (paper 3 in this volume)
OGS measured section no. 15374

OH-HA-0016 CONGRESS RUN

Stream cuts of Congress Run and tributary to Congress Run along Galbraith Road east of Winton Road; sec. 14, R. 1, T. 3, Cincinnati East and Cincinnati West, Ohio, 7.5-minute quadrangles (Ford, 1974); Springfield Twp., Hamilton County, Ohio; 39°13'00"N, 84°30'15"W; elevation at base: 603 ft (183.8 meters)

Units.—Miamitown, Fairview, Wesselman Tongue of Kope, North Bend Tongue of Fairview, plus (Ford, 1967, fig. 6): Kope

References.—Ford (1967), Diekmeyer (paper 3 in this volume), Dattilo (paper 7 in this volume)

OGS measured section no. 15373

OH-HA-0017 CROSBY ROAD

Road cuts on west and east sides of Crosby Road; sec. 13, T. 2 N., R. 1 E., Shandon, Ohio, 7.5-minute quadrangle; Crosby Twp., Hamilton County, Ohio; 39°16'00"N, 84°42'45"W; elevation at base: 627 ft (191 meters)

Units.—Miamitown (21 ft/6.4 meters), Fairview (63 ft/19.2 meters), Kope (32 ft/9.7 meters)

References.—Ford (1965, 1967), Diekmeyer (paper 3 in this volume), Dattilo (paper 7 in this volume)

OGS measured section no. 15379

OH-HA-0018 JACKSON HILL PARK

Hillside opposite 42 Mulberry Street, beneath crest of Jackson Hill Park, Cincinnati, Ohio; Jackson Hill is a spur of the hill called Mount Auburn; Rice and Gage Streets locality (OH-HA-0004) is located on next spur to north; Fractional R. 2, T. 3, Covington, Kentucky–Ohio, 7.5-minute quadrangle (Luft, 1971; Ford, 1974); Hamilton County, Ohio; 39°07'05"N, 84°30'50"W; elevation at base: 761 ft (232.0 meters)

Units.—Bellevue (6.7 meters/22 ft), Miamitown (1.2 meters/4.0 ft), Fairview (33.2 meters/109 ft), Kope (6.1 meters/20 ft)

References.—Ford (1967, p. 927, 929); Diekmeyer (paper 3 in this volume)

OH-HA-0019 MIAMI STATION

Highway cut south of "eng. sta. 480" (OGS measured section no. 15381), I-74 east, due south of Miami Station; sec. 1, R. 1, T. 1, Addyston Ohio–Kentucky, 7.5-minute quadrangle (Ford, 1972); Colerain Twp., Hamilton County, Ohio; 39°12'40"N, 84°41'25"W; elevation at base: 554 ft (168.9 meters)

Units.—Miamitown, Fairview (29 ft/8.8 meters), Wesselman Tongue of Kope (27 ft/8.2 meters), North Bend Tongue of Fairview (8 ft/2.4 meters), Kope (53 ft/16.2 meters), Grand Avenue Member of Kope (11 ft/3.4 meters)

References.—Ford (1965; 1967, p. 919, 925, 926), Diekmeyer (paper 3 in this volume)

OGS measured section no. 15381

OH-HA-0020 MUDDY CREEK

Composite of a number of individual exposures: 1—stream cut just south of Muddy Creek Road bridge 1.0 km (0.6 mile) east of junction of Muddy Creek Road and Ebenezer Road, in sec. 19; 2—creek bed and banks of Muddy Creek in sec. 25; 3—cliff section east of Muddy Creek in sec. 25; 4—cliff section north of Muddy Creek in sec. 19; 5—exposure 0.1 mile (0.2 km) south of the intersection of Muddy Creek Road and Devils Backbone Road, in sec. 25; secs. 19 and 25, T. 2, Fractional R. 2, Addyston, Ohio–Kentucky, 7.5-minute quadrangle (Ford, 1972); Green Twp., Hamilton County, Ohio; 39°07'45" to 39°08'00"N, 84°38'28" to 84°40'00"W; elevation at base: 533 ft (162.5 meters). NOTE: this creek is polluted and may contain raw sewage

Units.—Corryville, Bellevue (29 ft/8.8 meters), Miamitown (5 ft/1.5 meters), Fairview (67 ft/20.4 meters), Wesselman Tongue of Kope (4 ft/1.2 meters), North Bend Tongue of Fairview (20 ft/6.1 meters), Grand Avenue Member of Kope (12 ft/3.7 meters), Kope (106 ft/32.3 meters)

References.—Ford (1965; 1967, p. 919, 925, 926, 929), Jennette (1986), Diekmeyer (paper 3 in this volume), Dattilo (paper 7 in this volume), Goldman (paper 9 in this volume), Holland (paper 18 in this volume)

OGS measured section nos. 15376 (2), 15458 (3), 15459 (1)

OH-HA-0021 RIVERSIDE

Exposure in west branch of unnamed stream that enters Ohio River at Riverside, Cincinnati; base of section in stream bed north of intersection of Hillside Avenue and Tyler Street; sec. 10, Fractional R. 1, T. 3, Covington, Kentucky–Ohio 7.5-minute quadrangle (Luft, 1971; Ford, 1974); Delhi Twp., Hamilton County, Ohio; 39°04'35"N, 84°36'30"W; elevation at base: 606 ft (184.7 meters)

Units.—Fairview (39 ft/11.9 meters), Kope (81 ft/24.7 meters), Grand Avenue Mbr. of Kope (11 ft/3.4 meters)

References.—Ford (1965; 1967, p. 919, 925, 927), Diekmeyer (paper 3 in this volume)

OGS measured section no. 15384

OH-HA-0022 SEKITAN ROAD

Cliff section north of Sekitan Road and drainage channel 700 ft (213.4 meters) due east of first section; sec 8, Fractional R. 2, T. 1, Addyston, Ohio–Kentucky, 7.5-minute quadrangle (Ford, 1972); Hamilton County, Ohio; 39°08'40"N, 84°43'00"W; elevation at base: 566 ft (172.5 meters)

Units.—Miamitown, Fairview (26 ft/7.9 meters), Wesselman Tongue of Kope (14 ft/4.3 meters), North Bend Tongue of Kope (10 ft/3.0 meters), Kope (62 ft/18.9 meters), Grand Avenue Member of Kope

References.—Ford (1965; 1967, p. 919, 926); Diekmeyer (paper 3 in this volume)

OGS measured section no. 15377

OH-HA-0023 SHEITS ROAD

Exposures along two branches of an unnamed stream: 1—branch that follows Sheits Road, just west of intersection of stream and I-275 near Dornbusch, Ohio; 2—west-flowing branch and a portion of the branch of #1 crossing Sheits Road downstream of #1; secs. 21 and 15, R. 1, T. 1, Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Colerain Twp., Hamilton County, Ohio; 39°14'50"N, 84°37'24"W; elevation at base: 698 ft (212.8 meters)

Units.—Corryville (18.4 ft/5.6 meters), Bellevue (42 ft/12.8 meters), Miamitown (14 ft/4.3 meters), Fairview (38 ft/11.6 meters)

References.—Ford (1967, p. 919, 926), Diekmeyer (paper 3 in this volume), Dattilo (paper 7 in this volume), Goldman (paper 9 in this volume)

OGS measured section nos. 15380, 16872

OH-HA-0024 WEST FORK

Creek bed and banks of West Fork, Mt. Airy Forest; secs. 33 and 34, Fractional R. 2, T. 3, sec. 4, Fractional R. 2, T. 2, Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Hamilton County, Ohio; 39°09'30"N, 84°34'45"W; elevation at base: 530 ft (161.5 meters)

Units.—Miamitown, Fairview (43 ft/13.1 meters), Wesselman Tongue of Kope (11 ft/3.4 meters), North Bend Tongue of Fairview (19 ft/5.8 meters), Kope (110 ft/33.5 meters), Grand Avenue Member of Kope

References.—Ford (1965; 1967, p. 919, 925, 927), Diekmeyer (paper 3 in this volume)

OGS measured section no. 15383

OH-HA-0025 WYNBROOK APARTMENTS

Exposure behind (north of) Wynbrook Apartments east of Winton Road just north of intersection with Dutch Colony Drive, Cincinnati; Dutch Colony Drive is about 2.0 miles (3.2 km) north of intersection of Spring Grove Avenue and Winton Road; Cincinnati West, Ohio, 7.5-minute quadrangle

(Ford, 1974); Cincinnati, Hamilton County, Ohio; 39°11'25"N, 84°31'10"W
Units.—Mt. Auburn, Corryville, Bellevue, Miamitown
References.—Diekmeyer (paper 3 in this volume); Goldman (paper 9 in this volume)

OH-HA-0026 DORNBUSCH
Stream cut in west-flowing stream just north of town of Dornbusch and south-southeast of stream's intersection with I-275; Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Colerain Twp., Hamilton County, Ohio; 39°14'52"N, 84°36'30"W
Units.—Corryville (11.2 meters/36.7 ft)
References.—Goldman (paper 9 in this volume)
OGS measured section no. 16873

OH-HA-0027 McMILLAN STREET
Exposure in empty lot west of 16 McMillan Street and just northwest of junction of McMillan and Vine Streets, Cincinnati; Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Cincinnati, Hamilton County, Ohio; 39°07'39"N, 84°30'52"W
Units.—Corryville; this locality is in the type area of the Corryville
References.—Goldman (paper 9 in this volume)

OH-HA-0028 RAVINE STREET
Poor, mostly buried exposure behind Seminole Apartments southwest of intersection of Ravine and McMillan Streets, Cincinnati; Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Hamilton County, Ohio; 39°07'43"N, 84°31'36"W
Units.—Corryville
References.—Goldman (paper 9 in this volume)

OH-HA-0029 RUMPKE LANDFILL
Inaccessible (buried) exposure in field east of U.S. Route 27 N (Colerain Avenue), 2.5 km (1.5 miles) north of I-275; NW$^1/_4$ sec. 11, R. 1, T. 2, Greenhills, Ohio, 7.5-minute quadrangle; Colerain Twp., Hamilton County, Ohio; 39°16'33"N, 84°36'03"W
Units.—Corryville, Mt. Auburn (now buried as a result of landfill)
References.—Tobin (1982), Brandt Velbel (1985, loc. D), Goldman (paper 9 in this volume)

OH-HA-0030 SHARONVILLE
Exposure in upper half of field at Sharonville industrial park, situated at end of 800-foot (243-meter) lane (tram way) north of Hauck Road and 0.4 mile (0.7 km) east of intersection of Hauck and Reading Roads; Glendale, Ohio, 7.5-minute quadrangle; Sycamore Twp., Hamilton County, Ohio; 39°17'38"N, 84°24'07"W
Units.—Corryville, Miamitown, Bellevue, Fairview
References.—Goldman (paper 9 in this volume)

OH-HA-0031 WESTWOOD-NORTHERN BOULEVARD
Exposure in gully northwest of the junction of Westwood-Northern Boulevard and Gobel Street, Cincinnati; north end of Gobel Street has been closed off to traffic; Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Hamilton County, Ohio; 39°08'50"N, 84°39'45"W
Units.—? upper Corryville
References.—Goldman (paper 9 in this volume)

OH-HA-0032 GALBRAITH ROAD
Stream cut along Kugler Mill Road, the eastward continuation of Galbraith Road; SE$^1/_4$ sec. 25, R. 1, Twp. 5, Between the Miamis land survey, Madeira, Ohio, 7.5-minute quadrangle; Symmes Twp., Hamilton County, Ohio; 39°11'23" N, 84°18'32" W; elevation at base: 648 ft (197.5 meters)
Units.—Kope (2 ft/0.6 meter to base of Fairview)
References.—Ford (1965), Diekmeyer (paper 3 in this volume)
OGS measured section no. 13104

OH-HA-0033 GALBRAITH ROAD, CLIFF SECTION
Stream bed and banks of south tributary to Congress Run parallel to Hollyhock Drive, in city of Wyoming; sec. 14, R. 1, T. 3, Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Springfield Twp., Hamilton County, Ohio; 39°13'30"N, 84°30'15"W; elevation at base: 665 ft (202.7 meters)
Units.—Bellevue (20 ft/6.1 meters), Miamitown (7 ft/2.1 meters), Fairview (73 ft/22.3 meters), North Bend Tongue of Fairview (18 ft/5.5 meters), Kope (34 ft/10.4 meters)
References.—Ford (1965), Diekmeyer (paper 3 in this volume)

OH-HA-0034 EIGHTMILE CREEK
Stream exposures along Eightmile Creek near U.S. Route 52 up right fork subparallel to road to Cherry Grove; Withamsville, Ohio–Kentucky, 7.5-minute quadrangle; Anderson Twp., Hamilton County, Ohio; 39°33'20"N, 84°19'45"W; elevation at base: 476 ft (145.1 meters)
Units.—Weiss, Edwards, Norman, and Sharp (1965): Eden (140 ft/44.7 meters exposed below Maysville contact, below that another 50 ft/15.2 meters, mostly covered, to a 6-ft/1.8-meter ledge of Cynthiana Formation); Jennette (1986): Fairview (1.0 meter/3.3 ft), Kope (34.9 meters/114.5 ft)
References.—Weiss, Edwards, Norman, and Sharp (1965); Diekmeyer (paper 3 in this volume); Jennette (1986)
OGS measured section no. 13093

OH-HA-0035 MILLVALE
South end of bluff behind Millvale Court housing project on Beekman Street, Cincinnati; W$^1/_2$SW$^1/_4$ sec. 27, Fractional R. 2, T. 3, Between the Miamis land survey, Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Hamilton County, Ohio; 39°08'30"N, 84°33'15"W; elevation: 545 ft (166.1 meters)
Units.—Kope (106 ft/32.3 meters) in middle and upper parts
References.—Weiss, Edwards, Norman, and Sharp (1965), Diekmeyer (paper 3 in this volume)

OH-HA-0036 RAPID RUN
Stream cuts north of U.S. Route 50 (base near ford close to highway) and 0.25-km (0.16-mile) cut along Bender Road northeast of U.S. Route 50; secs. 23, 24, 29, Fractional R. 1, T. 3, Between the Miamis land survey, Burlington, Kentucky–Ohio, 7.5-minute quadrangle (Ford, 1972); Delhi Twp., Hamilton County, Ohio; 39°05'50"N, 84°40'15"W; elevation at base: 475 ft (144.8 meters)
Units.—Kope (202 ft/61.6 meters to base of Maysvillian)
References.—Ford (1965), Weiss, Edwards, Norman, and Sharp (1965), Diekmeyer (paper 3 in this volume)
OGS measured section no. 13106

OH-HA-0037 PABCO/TIMBERVIEW APARTMENTS
Two exposures: 1—outcrop behind Pabco Fluid Power Co., intersection of U.S. Route 50 and Bender Road; 2—outcrop behind Timberview Apartments, 5564 Hillside Avenue; sec. 29, Fractional R. 1, T. 3, Between the Miamis land survey, Burlington, Kentucky–Ohio, 7.5-minute quadrangle (Ford, 1972); Delhi Twp., Hamilton County, Ohio; 1—39°06'00"N, 84°40'20"W; 2—39°06'15"N, 84°40'40"W
Units.—Fairview (0.5 meter/1.6 ft), Kope (29.4 meter/96.5 ft)
References.—Jennette (1986), Diekmeyer (paper 3 in this volume)

OH-HA-0038 MONTANA AVENUE
Alternative name.—I-74/Montana Avenue
Road cut along eastbound entrance ramp onto I-74 from Montana Avenue; Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Cincinnati, Hamilton County, Ohio; 39°09'15"N, 84°33'45"W
Units.—Fairview (0.3 meter/1.0 ft), Kope 15.6 meters/51.2 ft)

References.—Jennette (1986), Diekmeyer (paper 3 in this volume)

OH-HA-0039 MT. AIRY FOREST

Series of large road cuts on either side of I-74, between mile 15.6 and mile 16.8, where highway passes through Mt. Airy Forest; sec. 4, Fractional R. 2, T. 2, Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974), Green Twp., Hamilton County, Ohio; 39°10'05"N, 84°34'52"W; 438000 N, 709000 E, UTM zone 16; NOTE: this is an interstate cut; permission from the Ohio Department of Transportation is required for close examination and sampling. Cut is steep and climbing it may be risky both to the geologist and to motorists

Units.—Corryville, Bellevue, Miamitown, Fairview, Kope

References.—Dattilo (paper 7 in this volume)

OH-HA-0040 DELHI PIKE

Exposure on north side of Delhi Pike opposite intersection with Mt. Alverno Road in sec. 5 (note that Mt. Alverno Road also intersects Delhi Pike in sec. 11); SW¼ sec. 5, Fractional R. 1, T. 3, Covington, Kentucky–Ohio, 7.5-minute quadrangle (Luft, 1971; Ford, 1974), Delhi Twp., Hamilton County, Ohio; 39°05'38"N, 84°35'35"W; 4329736 N, 708168 E, UTM zone 16

Units.—Miamitown, Fairview

References.—Dattilo (paper 7 in this volume)

OGS measured section no. 16879

OH-HA-0041 ASHTREE DRIVE AND HAMILTON AVENUE

Alternate designations.—Ashtree Shopping Center; Hamilton Avenue

Cut northwest of intersection of Ashtree Drive and Hamilton Avenue, Cincinnati; flat area in front of cut once was occupied by the Ashtree Shopping Center; for a time the building was the Southern Ohio College Technical Center, and a more recent tenant was the MTA School; W½NE¼SW¼ sec. 29, Fractional R. 2, T. 3, Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Cincinnati, Hamilton County, Ohio; 39°10'45"N, 84°32'50"W

Units.—lower Bellevue, Miamitown, Fairview

References.—Dattilo (paper 7 in this volume)

OH-HA-0042 BOUDINOT AVENUE

Construction exposure, now covered, two blocks south of intersection of Boudinot Avenue and Westwood-Northern Boulevard, Cincinnati; NE¼ sec. 9, Fractional R. 2, T. 2, Cincinnati West, Ohio, 7.5-minute quadrangle (Ford, 1974); Hamilton County, Ohio; 39°09'38"N, 84°36'07"W

Units.— Liberty (Brandt Velbel, 1985, fig. 2), Waynesville and Arnheim (Stephen H. Felton, personal commun., 1998)

References.—Brandt Velbel (1985, loc. G)

Ohio, Warren County

OH-WA-0001 CAESAR CREEK EMERGENCY OVERFLOW SPILLWAY

Emergency overflow spillway of Caesar Creek Reservoir; Oregonia, Ohio, 7.5-minute quadrangle; Warren County, Ohio; 39°28'49"N, 84°03'25"W; 4373976 m N, 753156 m E, UTM zone 16; elevation of uppermost exposed strata: 925 ft (281.9 meters); elevation of Clarksville Road in middle of spillway: 883 ft (269.1 meters)

Units.—Whitewater, Liberty, Waynesville

References.—Staursky (1981), Schumacher and Ausich (1983), Brandt Velbel (1985, loc. B), Schumacher, Shrake, Swinford, Brockman, and Wickstrom (1987, stop 5, p. 44, 52-55), Shrake (1992), Shrake, Schumacher, and Swinford (1988, p. 39-44), University of Dayton Department of Geology (1989, stop 4, p. 8-10); Shrake and Schumacher (1989), Schumacher, Shrake, Swinford, Rockwell, and Cuffey (paper 13 in this volume), Holland (paper 18 in this volume)

OH-WA-0002 CAESAR CREEK GORGE

Alternate name.—Caesar Creek Dam

Cut in gorge below dam of Caesar Creek Reservoir; Oregonia, Ohio, 7.5-minute quadrangle; Warren County, Ohio; 39°29'05"N, 84°03'49"W; 4374458 m N, 752555 m E, UTM zone 16; elevation at base: 755 ft (230.1 meters)

Units.—Waynesville, Arnheim

References.—Schumacher and Ausich (1983), Shrake (1992), Schumacher, Shrake, Swinford, Brockman, and Wickstrom (1987, p, 52-55), Shrake, Schumacher, and Swinford (1988, p. 39-44), University of Dayton Department of Geology (1989, stop 3, p. 7-8); Schumacher, Shrake, Swinford, Rockwell, and Cuffey (paper 13 in this volume), Holland (paper 18 in this volume)

OH-WA-0003 FLAT FORK CREEK

Stream bed and vertical cut banks of Flat Fork Creek (southeast of Caesar Creek Reservoir); Oregonia, Ohio, 7.5-minute quadrangle; Massie Twp., Warren County, Ohio; 39°28'47"N, 84°03'00"W

Units.—lower Whitewater, Liberty, topmost Waynesville; before Caesar Creek was dammed in 1978, the complete section from the Arnheim to the Whitewater was exposed in Flat Fork Creek

References.—Wolford (1930), Schumacher, Shrake, Swinford, Brockman, and Wickstrom (1987, p. 52-55)

OH-WA-0004 LICK RUN

Stream exposures along Lick Run west of Ohio Route 132 bridge and 760 meters (2500 ft) north of Blackhawk, at junction of Ohio Routes 132 and 123; Pleasant Plain, Ohio, 7.5-minute quadrangle; Harlan Twp., Warren County, Ohio; 39°20'02"N; 84°04'41"W

Units.—Mt. Auburn, Corryville; measured section in Krumpolz (1980, p. 182-189)

References.—Krumpolz (1980, loc. 3), Goldman (paper 9 in this volume)

OH-WA-0006 SECOND CREEK

Stream cuts along Second Creek below and west of Cozzandale Road bridge; Pleasant Plain, Ohio, 7.5-minute quadrangle; Harlan Twp., Warren County, Ohio; 39°19'25"N, 84°05'31"W

Units.—Mt. Auburn, Corryville

References.—Osgood (1970), Goldman (paper 9 in this volume)

OH-WA-0007

Stream-bank exposures along north fork of Harpers Run, off Strout Road at Camp Whip-Poor-Will G.S.A. outdoor center; Oregonia, Ohio, 7.5-minute quadrangle; Washington Twp., Warren County, Ohio; 39°23'N, 84°05'W

Units.—"*Treptoceras duseri* shale unit," Waynesville

References.—Frey (1987a, loc. E; 1987b, loc. 2)

OH-WA-0008

South-facing road cut along U.S. Route 42, 3 km (1.9 miles) northeast of Waynesville; SW¼SW¼ sec. 26, T. 4, R. 5, Waynesville, Ohio, 7.5-minute quadrangle; Washington Twp., Warren County, Ohio

Units.—"*Treptoceras duseri* shale unit," Waynesville

References.—Frey (1987a, loc. F); see also Frey (1987b, loc. 1)

ALPHABETICAL LIST BY LOCALITY NAME

Aiken School (OH-HA-0012)
Armco Steel (OH-BU-0001)
Arnold Creek (IN-O-0002)
Ashtree Drive and Hamilton Avenue (OH-HA-0041)
Ashtree Shopping Center (see Ashtree Drive and Hamilton Avenue, OH-HA-0041)
Aurora (IN-D-0001)

Backbone Creek (OH-CT-0006)
Bald Knob (OH-HA-0013)
Batavia #1 (OH-CT-0001)
Batavia #2 (OH-CT-0002)
Bear Creek (OH-CT-0010)
Beckjord (OH-CT-0019)
Bellevue Hill (OH-HA-0003)
"Big 4" railroad cut (see Maud cut, OH-BU-0002)
Blue Rock Road (OH-HA-0005)
Boat Run (OH-CT-0011)
Bon Well Hill (IN-FR-0001)
Boudinot Avenue (OH-HA-0042)
Bradford (KY-BK-0001)
Brent (KY-CP-0001)
Briarly Creek (OH-HA-0014)
Brookville Dam spillway (IN-FR-0002)
Brookville North (see Garr Hill, IN-FR-0003)

Cabin Creek (KY-LW-0001)
Caesar Creek emergency overflow spillway (OH-WA-0001)
Caesar Creek gorge (OH-WA-0002)
Camp Claybanks (OH-HA-0015)
Causeway Road (see Fairfield Causeway, IN-FR-0004)
Chicken Hollow (OH-BR-0001)
Chilo (OH-CT-0012)
Christ Hospital (see Rice and Gage Streets, OH-HA-0004)
Clifton Hill (see Bellevue Hill, OH-HA-0003)
Congress Run (OH-HA-0016)
Covington (KY-KE-0004)
Cowan Lake (OH-CN-0001)
Crosby Road (OH-HA-0017)

Delhi Pike (OH-HA-0040)
Devou Park (see Wayne Road, KY-KE-0006)
Dornbusch (OH-HA-0026)

Eagle Creek (OH-BR-0005)
East Fork Reservoir spillway/Wm. A. Harsha Lake (OH-CT-0007)
Eightmile Creek (OH-HA-0034)
Elk Creek (OH-BU-0003)
Elkhorn Creek (IN-WY-0008)
Elkhorn Falls (IN-WY-0004)
Emming Street (OH-HA-0002)
Excello (see Middletown, OH-BU-0005)

Fairfield Causeway (IN-FR-0004)
Fairfield Road (see Fairfield Causeway, IN-FR-0004)
Fairview Park (OH-HA-0001)
Flat Fork Creek (OH-WA-0003)
Fort Thomas (KY-CP-0001)
Foster (KY-BK-0003)

Galbraith Road (OH-HA-0032)
Galbraith Road, cliff section (OH-HA-0033)
Garr Hill (IN-FR-0003)
Georgetown (OH-BR-0006)
Goose Run (OH-BR-0007)
Grand Avenue (OH-HA-0006) (see also Newport-Grand Avenue, KY-CP-0004)

Hamilton Avenue (see Ashtree Drive and Hamilton Avenue, OH-HA-0041)
Happy Hollow (OH-CT-0013)
Harrison (OH-HA-0007)
Harsha, Wm. A., Lake (see East Fork Reservoir spillway, OH-CT-0007)
Hunts Creek (OH-BU-0004)

I-75/Covington (see Covington, KY-KE-0004)
I-275/Kentucky Route 9 (see Johns Hill, KY-CP-0005)
I-275/Turkeyfoot Road (KY-KE-0005)
I-275 East/Kentucky Route 445 (see Fort Thomas, KY-CP-0001)
I-471/Grand Avenue (see Newport-Grand Avenue, KY-CP-0004)
I-471/U.S. Route 27 (see Southgate, KY-CP-0003)
Indiana Route 1 (see Southgate Hill, IN-FR-0005)
Indian Creek (OH-CT-0014)
Isaacs Creek (see Manchester, OH-AD-0003)

Jackson Hill Park (OH-HA-0018)
Johns Hill (KY-CP-0005)

Kope Hollow (OH-BR-0003)

Lawrenceburg (KY-BE-0003)
Lick Run (OH-WA-0004)
Light, William, Paving Company quarry (OH-CT-0005)
Madison-Hanging Rock (IN-JE-0006)
Madison-Indiana Route 56 (IN-JE-0004)
Madison Middle road cut (IN-JE-0002)
Madison North road cut (IN-JE-0001)
Madison-Riley Creek (IN-JE-0005)
Madison South road cut (IN-JE-0003)
Mall Road (KY-BE-0001)
Manchester (OH-AD-0003)
Maud cut (OH-BU-0002)
Maysville-Kentucky Route 11 (KY-MS-0002)
Maysville-U.S. Routes 62 & 68 (KY-MS-0004)
Maysville bryozoan reef mounds (KY-MS-0006)
McMillan Street (OH-HA-0027)
Meldahl Dam (KY-BK-0002)
Miami Station (OH-HA-0019)
Miamitown/Hamilton-Cleves exit (OH-HA-0009)
Miamitown West (OH-HA-0008)
Middlefork Reservoir (IN-WY-0007)
Middletown (OH-BU-0005) (see also West Middletown, OH-BU-0006)
Millvale (OH-HA-0035)
Montana Avenue (OH-HA-0038)
Mt. Airy Forest (OH-HA-0039)
Muddy Creek (OH-HA-0020)

Newport-Grand Avenue (KY-CP-0004)
Newport Shopping Center (KY-CP-0002)
Ninemile Creek (OH-CT-0015)
North Bend (OH-HA-0010)
North Point Pleasant (OH-CT-0016)

O'Bannon Creek (OH-CT-0008)
Ohio Brush Creek, West Fork (OH-AD-0002)
Orphanage Road (KY-KE-0003)

Pabco/Timberview Apartments (OH-HA-0037)
Point Pleasant (OH-CT-0020) (see also North Point Pleasant, OH-CT-0016)

Rabbit Hash (KY-BE-0002)
Rapid Run (OH-HA-0036)
Ravine Street (OH-HA-0028)
Red Oak Creek (OH-BR-0004)
Rice and Gage Streets (= Christ Hospital) (OH-HA-0004)
Richmond-U.S. Route 27 (IN-WY-0001)
Riedlin Road/Mason Road (KY-KE-0001)
Ripley (OH-BR-0002)
Ripley #2 (OH-BR-0008)
Rising Sun (IN-O-0001)
Riverside (OH-HA-0021)
Rumpke Landfill (OH-HA-0029)

St. Leon (IN-D-0002)
Second Creek (OH-WA-0006)
Sekitan Road (OH-HA-0022)
Sharonville (OH-HA-0030)

Addresses of authors: Richard Arnold Davis, Biology Department, College of Mount St. Joseph, 5701 Delhi Road, Cincinnati, OH 45233-1670; Sharon C. St. Louis Diekmeyer, Department of Geology, University of Cincinnati, Cincinnati, OH 45221-0013; Benjamin F. Dattilo, Geoscience Department, Weber State University, 2507 University Circle, Ogden, UT 84408-2507; Lawrence I. Goldman, MINEsoft, Ltd., 165 S. Union Blvd, #510, Lakewood, CO 80228; Steven M. Holland, Geology Department, University of Georgia, Athens, GA 30602; Roger J. Cuffey, Department of Geosciences (Deike Building), Pennsylvania State University, University Park, PA 16802.

APPENDIX B.—BIBLIOGRAPHY ON THE TYPE-CINCINNATIAN

by Richard Arnold Davis and Richard A. Spohn

INTRODUCTION

The literature relating to the type-Cincinnatian is massive and far flung. It ranges from huge monographs to casual mentions, *en passant*, in works devoted to other topics. We long ago gave up hope of compiling a truly comprehensive bibliography. We have tried to list all of the major and semi-major works, but we have not ignored minor mentions when they came our way. Certainly we have missed some works. We hope that none of these are your favorites nor those truly critical to your research.

One known source of information on the type-Cincinnatian has not been included here: the 1:24,000-scale open-file maps of the Ohio Division of Geological Survey. Reconnaissance-level bedrock-geology, bedrock-topography, and structure-contour maps are available for all of the 7.5-minute quadrangles in southwestern Ohio, and, in fact, for all of Ohio.

An especial concern has been unpublished theses and similar works. In the end we opted to include such items, but not without some discomfort. First of all, such materials are more difficult for the potential reader to obtain than are published works. Second, it is harder even to learn of the existence of such items—hence, we certainly missed many of them, so the bibliography is far from comprehensive in the coverage of unpublished material.

We have endeavored to verify every citation with the actual work cited. In some instances this has not been possible, particularly with unpublished works. Hence, we apologize, in advance, for any errors in the citations.

Some readers may find it frustrating that authors are not cited in a consistent format. We deliberately decided to try to list each author as he or she was listed in the actual publication. Thus, in some cases, the first name of an author is spelled out, whereas, in other instances, only initials are given.

Compiling a bibliography such as this one can be aided greatly by colleagues willing to share their carefully hoarded lists of references. Douglas L. Shrake, of the Ohio Division of Geological Survey, generously made available the ongoing compilation of references on the Cincinnatian that he and others at the Survey have put together over the years. Steven M. Holland, of the University of Georgia, likewise provided a list of references he compiled. Richard Fuchs, of the Cincinnati Dry Dredgers, passed on citations to references he has located in his long-term study of Cincinnati scolecodonts. Merrianne Hackathorn, of the Ohio Division of Geological Survey, added some references and corrected many others, particularly adding missing information for theses and dissertations. Stig M. Bergström, of The Ohio State University, provided a list of additional references. We are grateful especially to those individuals, but also to the many others who, with the simple phrase, "Have you seen the paper . . . ?", helped make this compilation better than it might have been. It would be unfair not to give recognition to the many, many folks who have helped make the various printed comprehensive bibliographies of geology and GeoRef the extraordinarily valuable tools they are to all geologists. Hats off to them all!

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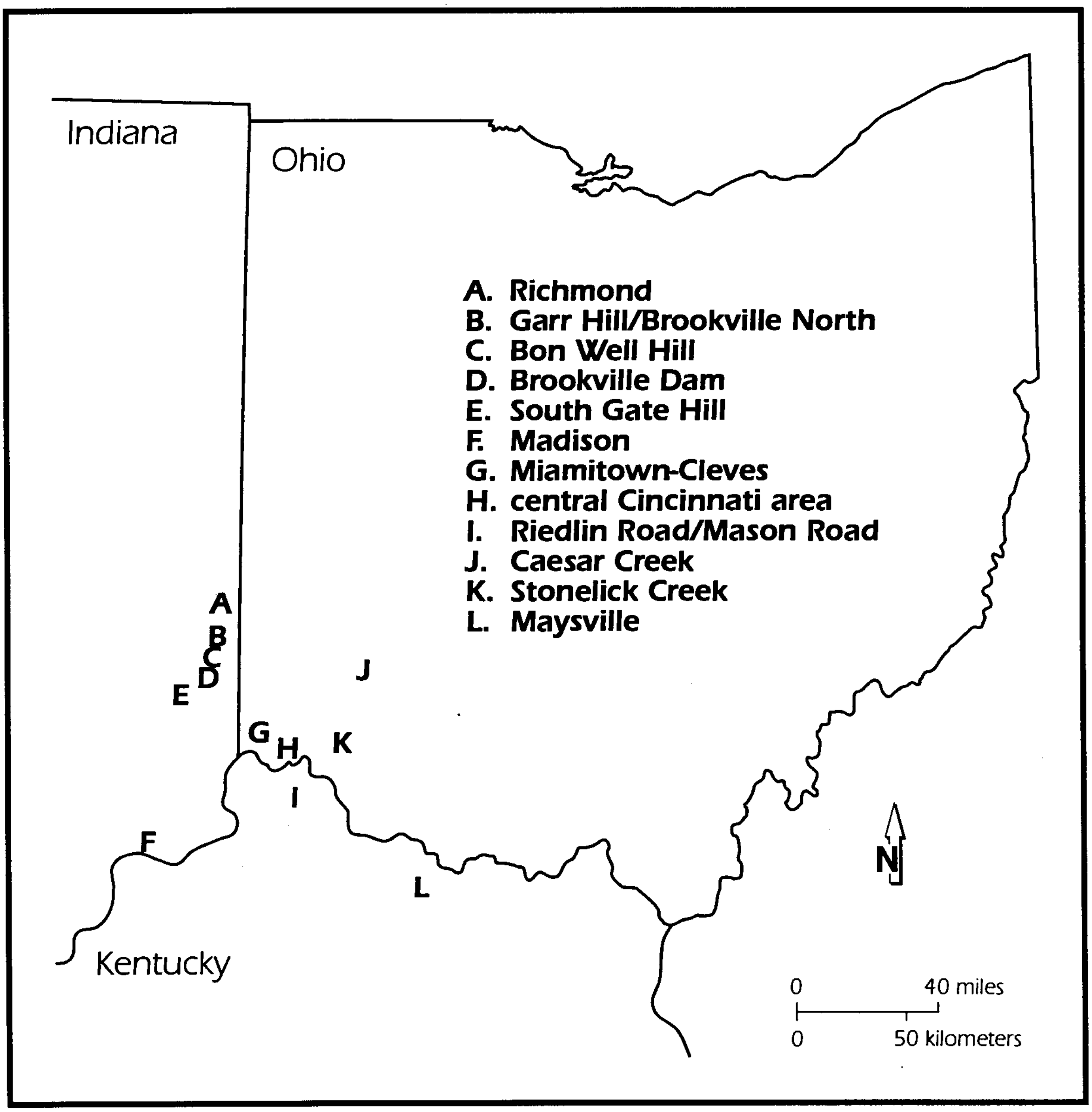
Addresses of authors: Richard Arnold Davis, Biology Department, College of Mount St. Joseph, 5701 Delhi Road, Cincinnati, OH, 45233-1670; Richard A. Spohn, Geology/Physics Library, University of Cincinnati, Cincinnati, OH 45221-0153.

MAP OF THE TRI-STATE AREA SHOWING MAJOR LOCATIONS DESCRIBED IN THIS GUIDEBOOK



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